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VOL. XXXVII. — No. 1. JANUARY 1960.

Monthly Bulletin of the International Railway Congress Association

(English Edition)

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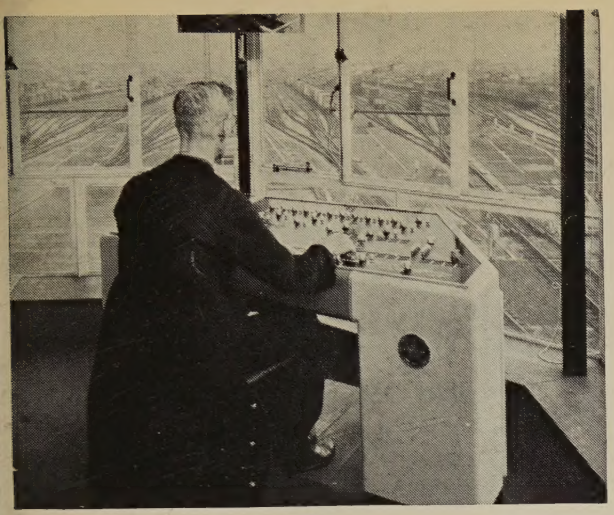

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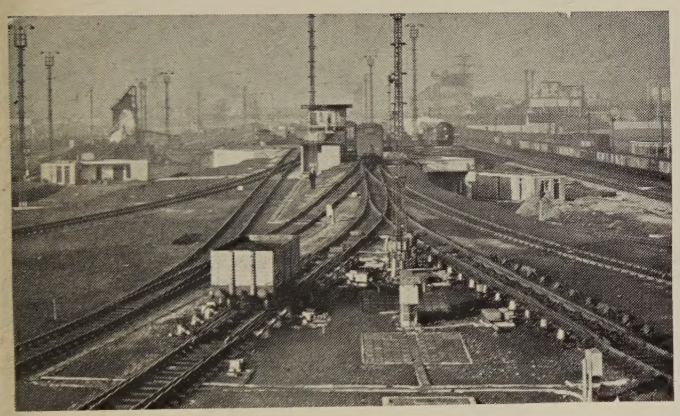

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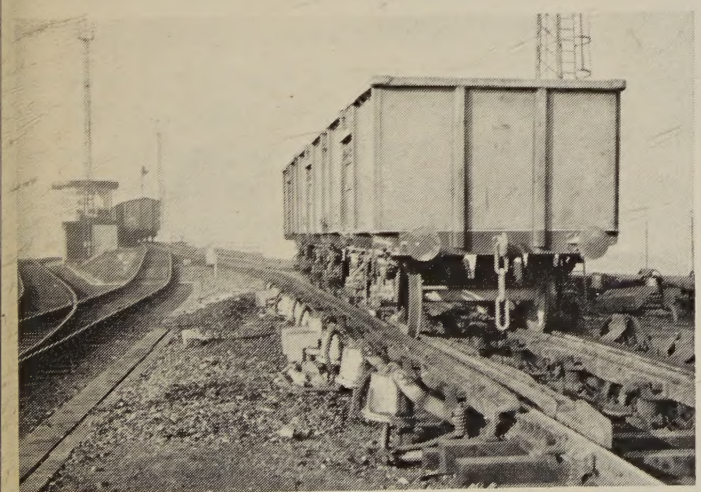

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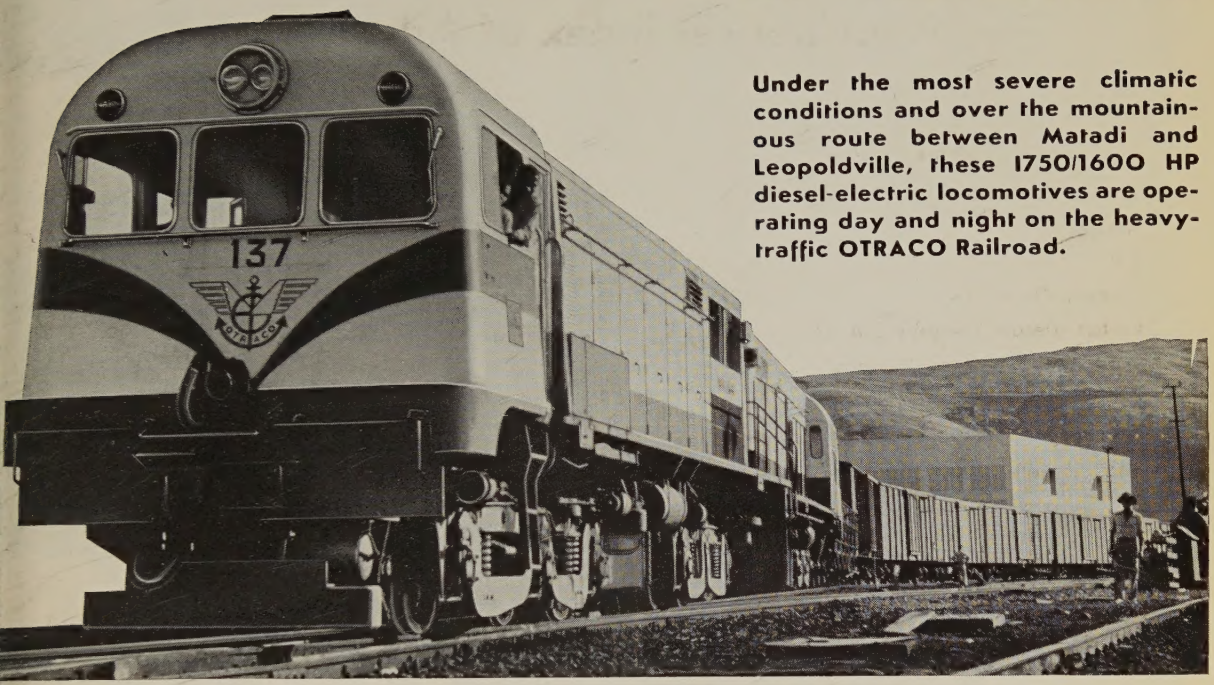

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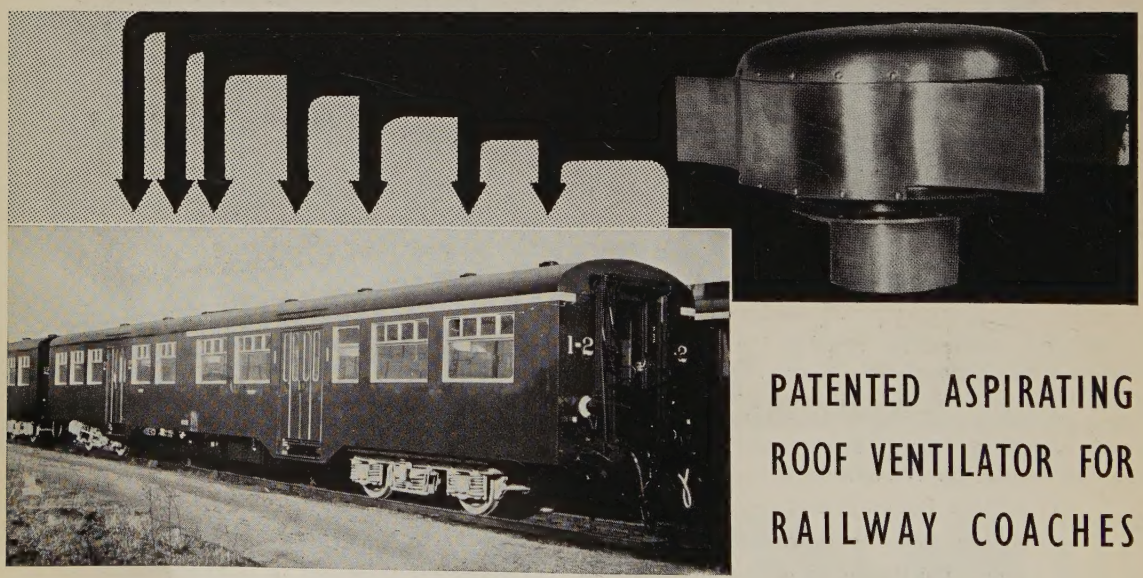

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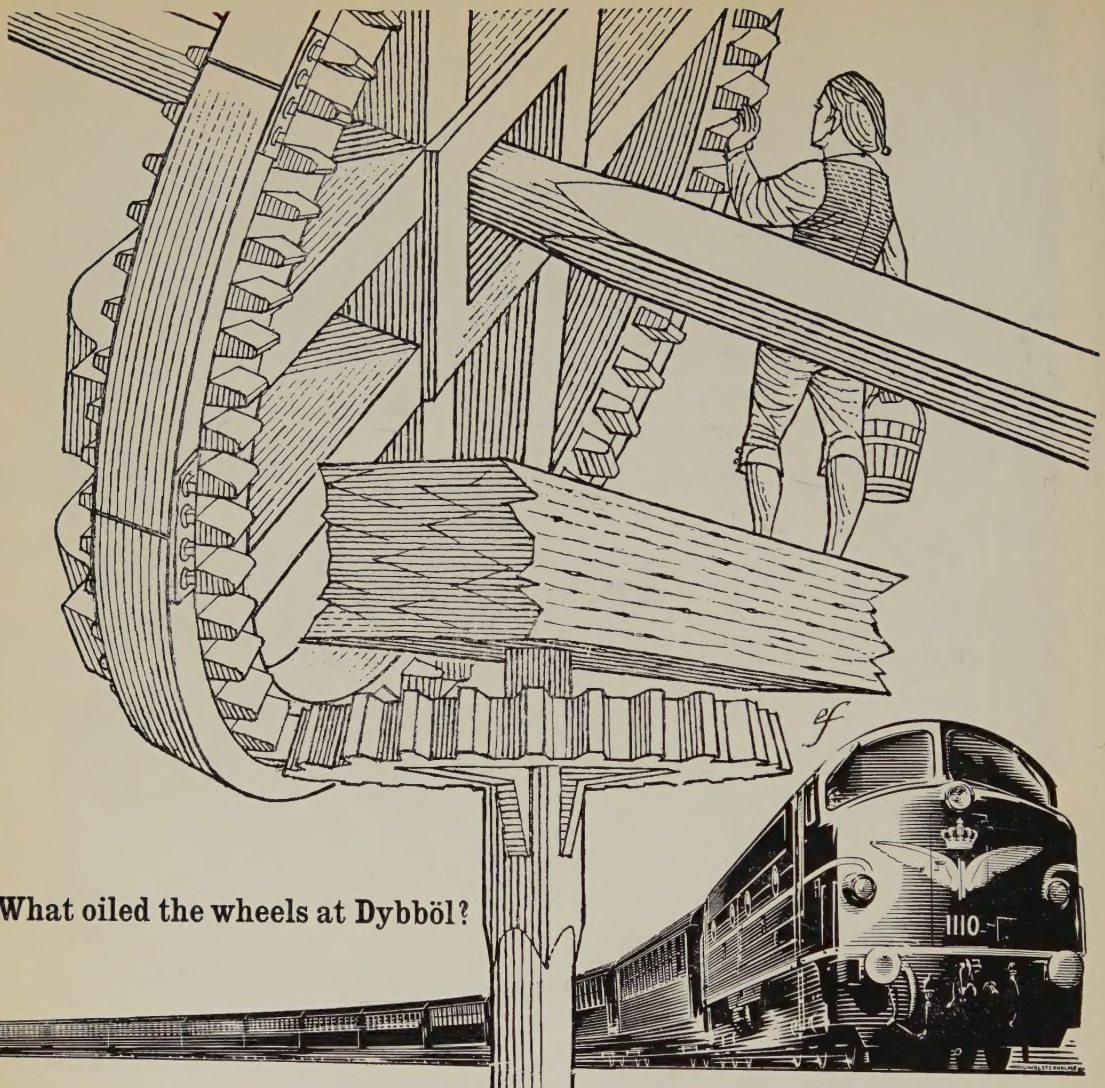

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MONTHLY BULLETIN

OF THE

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

(ENGLISH EDITION)

PUBLISHING and EDITORIAL OFFICES : 19, RUE DU BEAU-SITE, BRUSSELS

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Advertisements : All communications should be addressed to the Association, **19, rue du Beau-Site, Brussels.**

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An edition in French is also published.

Vol. XXXVII. — No. 1. January 1960.

BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
ASSOCIATION
(ENGLISH EDITION)

[656 .225]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

ENLARGED MEETING OF THE PERMANENT COMMISSION
(BRUSSELS, 1960).

QUESTION 3.

Transport on railway wagons of road-lorries and trailers loaded with goods.

Questions arising from this mode of transport :

- **The role of the road-hauliers;**
- **Tariffs to be applied;**
- **Characteristics of the railway rolling stock to be employed;**
- **Installations for loading and unloading;**
- **Use of single wagons, or of sets of wagons, or of complete trains for this kind of transport.**

Results already obtained and possibilities of extending this mode of transport.

REPORT

(America (North and South), Australia, Burma, Ceylon, Egypt, Federal Republic of Germany, Ghana, India, Indonesia, Irak, Iran, Republic of Ireland, Japan, Malaya, Netherlands, New Zealand, Norway, Pakistan, Philippines, South Africa, Sudan, Sweden, United Kingdom of Great Britain and Northern Ireland and dependent overseas territories, Union of Soviet Socialist Republics),

by Dr. G. SCHRADER,

Bundesbahnoberrat in der Hauptverwaltung der Deutschen Bundesbahn, Frankfurt (Main), Germany.

I. Introduction.

The transport of loaded road-lorries and trailers on railway wagons, herein referred to as piggy-back or TOFC — « trailer on flat car » traffic is increasing in importance. This new type of transport provides an excellent technical solution for the problem of door-to-door traffic and above all enables the coordination and co-exi-

stence of rail and road transport. It will bring back traffic to the railways, and will relieve the roads.

One reporter each have been appointed for French speaking countries and for English speaking countries. Both reporters have drafted a uniform questionnaire, which was forwarded to all affiliated Railway Administrations. Excepting a few Administrations which have not sent a reply, the following Administrations stated that they have no information to give on the subject matter :

Ceylon Government Railway;
Indonesian Republic Railways;
State Railways of Uruguay;
U.S.S.R. State Railways;
Swedish State Railways;
Iranian State Railways;
Coras Iompair Eireann;
Egyptian Railways;
Iraqui State Railways;
London Transport Executive;
Malayan Railway;
Manila Railroad Company;
Nigerian Railway;
New Zealand Government Railways;
Nyasaland Railways Limited;
Union des Chemins de fer Privés Suédois;
Victorian Government Railways.

The following thirteen Administrations or Organisations have sent their comments on this question :

Association of American Railroads;
British Railways;
Argentine State Railways;
Norwegian State Railways;
Netherlands Railways;
Deutsche Bundesbahn;
East African Railways and Harbours;
Japanese National Railways;
Rhodesia Railways;
South African Railways and Harbours;
Sudan Railways;
Tasmanian Government Railways;
Indian Government Railways.

The last mentioned Railway Administrations have studied the problem of transporting loaded road vehicles on railway wagons. However, regular TOFC service has been introduced only in the United States, Canada, Federal Germany, South Africa, and to a limited extent in Great Britain. In Argentine, this system of transportation is now on trial.

II. Technical questions.

The difficulties experienced in almost all countries with regard to the introduction of TOFC traffic are due to the limited railway moving profile which in turn is governing the loading gauge. It should be noted, that TOFC traffic has made progress and gained importance in countries which have a large loading gauge, particularly in the United States and Canada. The loading gauge or clearance governing in most European railways is the one established by the Technical Unit of Railways (TE), 1954, issue. Appendices 1 to 5 show the loading gauges for Germany, Great Britain, the Netherlands, Japan and South Africa.

Of much importance for the operation of TOFC traffic are also the technical characteristics of road vehicles, which in all countries are subjected to different legal regulations. The Economic Commission for Europe (ECE) concluded under date of 19 September 1949 the « Convention for Road Transport » which in article No. 23 provides, that the maximum dimensions and total weights of the vehicles permitted to operate on the roads of the contracting countries shall be established by legal regulations of the individual governments. Excepted are a few *single roads* to be specified in regional agreements between the countries concerned and for which the maximum dimensions and total weights of Appendix 7 to the Convention apply. Thus, the 1949 Convention affords, on this point, complete liberty to national legislation. An European agreement concluded in 1950 is only in force amongst France, the three Benelux countries, Yugoslavia and Greece. The minimum dimensions and weights established in these countries are not less than those stated in Appendix 7 to the « Convention ». However, there are countries such as Austria, Switzerland, and the Scandinavian countries where smaller limits have been

fixed. Federal Germany, where permissive dimensions and weights for lorries and trailers have been relatively large has, for the purpose of preserving and relieving the roads, considerably reduced these dimensions by a new act dated 29 March 1956 taking effect for new vehicles as from 1 January 1958 and for all road vehicles (allowing a certain transitory period) as from 1 July 1960.

Table I shows the dimensions and weights applicable for road motor vehicles in Federal Germany, the Netherlands, Great Britain and the United States of America.

Important for the development of TOFC traffic is not only the type and number of lorries and trailers operated in the different countries but also the number of these owned by each of the railways, professional hauliers (transporting on behalf of a third party) or by privat undertakings (transporting on own account). Lorries and trailers having a pay load of less than 3 tons will generally not be considered for TOFC traffic. Maximum economy will be obtained in TOFC traffic by transporting lorries and trailers with a loading capacity of not less than 15 tons when moved as complete railway carloads.

Tractor-trailer units (tractor and semi-trailer) are preferred in the USA and Canada for TOFC traffic, since the traction vehicle may be separated from the load carrying trailer, thus affording savings through rational employment of tractors and personnel (one tractor for several trailers). In European countries, the standard type lorry-trailer units are still widely used for road transports which, due to their general design, are less suitable for TOFC traffic. However, in Europe too, the trend toward the tractor semi-trailer unit is quite noticeable, and is supported by almost all governments with a view to greater safety on the roads.

Table No. II shows the total number of the different types of lorries and trailers licensed in Federal Germany and the Netherlands.

It should be noted, that the share of road transport in the total freight traffic is increasing in almost all countries while the railways' share is declining. This development indicates, that it will be necessary for the railways to furnish their customers, even where no private sidings are available, door-to-door service by introducing TOFC transportation.

Table No. III illustrates the evolution of goods traffic on rail and road in Federal Germany, the Netherlands, and Japan during the years between 1950 and 1957.

There are various technical feasibilities for transporting lorries and trailers loaded with goods on railway wagons.

1) The most simple and ideal method, namely, transporting road vehicles of standard design on standard railway wagons, is in most countries barred by loading gauge restrictions.

   Standard type semi-trailers are transported on standard type flat cars having a length of from 40 to 50 feet (12.2 to 15.2 m) only in the USA and Canada. The railways of these two countries also use special flat cars of from 75 to 88 feet (22.9 to 26.8 m) in length, able to carry two and more trailers;

2) Rather extensive use is made in TOFC traffic of *specially designed road vehicles suitable to be transported on standard type railway flat cars.* The design of these special road vehicles is such, that, with running gear attached, they will not exceed the railway loading gauge or they will permit the body to be lifted from the running gear and placed on the railway flat car for rail transport. The running gear is either transported with the trailer body or left at the terminal station.

   Since 1956 the German Federal Railway currently use for their TOFC traffic about 60 special semi-trailers of the types « Burger » and « von Lienen » each having a loading capacity of between 16 tons and 17 tons. Only the body with its load is transported by rail, while the running gear is left

at the departure terminal. The body of the semi-trailer is loaded on the railway car with a hydraulic attachment. Details may be noted from photographs 1) to 3) of Table IV.

There are also on the DB other similar types of semi-trailers, such as the Kögel-Wortman type, which is fitted with rollers attached to the body. The loaded body is rolled laterally on the wagon and the running gear and tractor remain in the station. Table IV and Figures 4 and 5 show details of this semi-trailer.

Special road vehicles of various designs are also used in the *USA* and *Canada* for TOFC traffic.

The « Clejan » system requires trailers with special devices which are carried on special railway flat cars having a central sole bar.

The « Mo-Pac » system makes use of detachable trailer bodies which are loaded on railway flat cars with gantry cranes.

Special road vehicles are also used in *Great Britain* (see Appendix to Table IV) for TOFC traffic, particularly for the conveyance of liquids. Owing to the small loading gauge of the British Railways, progress in TOFC traffic is much impeded and the trend is more toward container traffic.

Remarkable is the extensive use made by the South African Railways of mobile container-trailers, where 250 units of these trailers with a loading capacity of 5 tons each (see Appendix to *Table IV*) are currently in operation in TOFC traffic;

3) Another technical possibility is the *transport of standard type road vehicles on special railway cars.* Such special flat cars have a much lower than normal platform and will permit the transportation of standard road vehicles without the loading gauge being exceeded. The German Federal Railway have two of these « low floor » units and an additional four, made up of four links or articulated units each — the number of the links may be increased at random — are on order and are expected to be taken into operation some day early in 1960. This type of special railway cars seems to be especially suitable for the extension of the TOFC traffic on railway networks with a very restricted loading gauge, because it avoids the purchase of and additional investments in special road vehicles by hauliers. Technical details are given on the diagram of *Table No. IV*;

4) TOFC traffic may also be operated with *special type road vehicles carried on special railway cars.* A typical example for this method of transport is the « Flexi-Van » system used in the USA.

This system employs special semi-trailers with detachable bodies which are loaded without their wheel assembly on special flat cars fitted with a turntable. It should be emphasized, that such a system requires additional investments in both the special road vehicle and the special rail vehicle;

5) As a last and technical optimal solution should be mentioned the combined road-rail vehicles. These are railway goods wagons and road vehicles, fitted with running gears which enable them to operate either on rails or on the road.

The German Federal Railway are testing 6 of these combined rail-road vehicles, four of them are of latest design and have a loading capacity of 15 tons. The « Schöttler - Schneider - WMD » designs are semi-trailers, which, for the movement on rails are placed on special running gears, while their road wheels are turned upward and locked. The movement of these vehicles is somewhat restricted, due to the fact, that transfer from road to rail is possible only at points where the gears for running on rails are kept available. Compared with this design the combined rail-road vehicle type « Uerdingen » is completely unrestricted in its movements because its railway bogies have rubber tyres

attached for running on the road. Their drawback is the additional weight of the railway bogies which remain with the vehicle when running on the road. The photographs Nos. 6 to 9 of *Table IV* illustrate the technical details of these interesting combined rail-road vehicles.

In the USA, combined rail-road vehicles are employed by the « Railvan » system. They are semi-trailers, fitted with both a railway wheel set and a road wheel set. Within the train consist they are running with the front end of each body coupled to the rear end of the body ahead. Being of light weight construction, their total weight is 16 tons and they carry a pay load of 11 tons. Operation on the road to and from the railway terminal is with standard type tractors.

It is understood that the British Railways will undertake trials with the « Railvan » system before the end of this year. Reproductions of the vehicles used are shown on the Figures Nos. 10 to 12.

The difficulties arising in connection with the combined rail-road vehicles concern dimensions and weights, which under pertinent regulations differ considerably for road vehicles and railway rolling stock respectively, and which have to be coordinated. An entirely satisfactory solution will be hard to find. It should also be considered, that rail-road vehicles will probably have to be purchased by the railways, for it seems not likely, that professional road hauliers will procure this special type of vehicles.

III. Organisation.

TOFC traffic may be handled by the railways either with road vehicles belonging to them, owned by professional road hauliers, or by private firms.

With regard to the technical solution and the handling of TOFC traffic, different systems are employed in the individual countries. In many of them several systems are operated simultaneously. In Federal Germany, the TOFC traffic is now carried out with railway owned road vehicles as an experiment for gaining technical and commercial experience. However, the primary aim in Germany is for cooperation with licensed common road hauliers. Therefore, it is the intention of the railways to withdraw their own road vehicles from TOFC traffic, immediately a sufficient number of professional road hauliers participate in this mode of transport. The basic conception is, that the railways shall furnish the railway cars and the road hauliers shall supply the road vehicles. It is not considered to render TOFC service to private firms handling transports on their own behalf, nor will private companies be employed as intermediaries between the railways and road hauliers.

TOFC traffic in the *USA and Canada* is handled with both railway owned road vehicles and road vehicles owned by professional truckers. Also carried in TOFC service are road vehicles belonging to private firms (traffic on own account). Trailers are carried on railway owned and privately owned railway flat cars.

The railway cars used in *Great Britain* for TOFC traffic are the property of the British Railways, while the road vehicles are furnished either by the British Railways of the shippers.

TOFC traffic in South Africa is handled exclusively with railway owned mobile container-trailers.

IV. Operating.

Since it is the object and purpose of the TOFC system to cover the long distances by rail, it seems logical, that the distances over which collection and delivery is made to and from railway terminals shall be short.

In Federal Germany, the distances over which shipments are collected and delivered over the road are generally less than 30 km. No maximum distance is fixed but, a long distance trucker's license must have been obtained if transports are carried beyond a radius of 50 km from the point where the road vehicle is stationed.

In the USA, shipments transported in railway owned road vehicles under the TOFC system shall be collected and delivered over distances generally not to exceed 30 miles = 48 km. In Great Britain, the average distance for delivery and collection over the road is 5 miles = 8 km and shall in no case exceed 25 miles = 40 km.

On the rail, TOFC traffic is generally operated between large junction points or traffic centers. In exceptional cases, it may also be extended to scattered points.

In view of the time lost in transferring trailers from the road to the railway wagon and vice versa, TOFC traffic will be economical only if rail movement over a minimum distance is ensured. The distances over which trailers are moved by rail under the TOFC system range in the USA and Canada from 150 miles = 240 km to as much as 1 000 miles = 1 600 km. The average rail movement in TOFC traffic amounts to 240 miles = 400 km.

In Federal Germany, the mean distance over which TOFC traffic is moved by rail is roughly 400 km.

The method of railway transport (single wagons, groups of wagons, or complete trains) depends, in each case, on the amount of TOFC traffic offered. In a few cases, trailers are transported on single wagons, in the majority of the cases, they are moved in groups of railway cars. In the USA and in Canada, the railways are operating between large terminals complete trains of flat cars loaded with trailers. This is also the goal aimed at in Federal Germany.

Flat cars loaded with TOFC trailers should be included in fast freight trains so as to equal or undercut the overall transport time taken by road hauling. Inclusion of such cars in passenger trains is not considered. Whether the overall transport time will be longer or shorter in TOFC traffic than the road haul time will depend on the circumstances prevailing. In general, it may be said, that over distances of less than 300 km the time taken for transport by road is shorter.

In the USA and Canada including also Federal Germany, the drivers of the road vehicles are not riding in the train on which the trailers are transported. It is one of the advantages of TOFC traffic, that no motive power and staff is required during the transport by rail.

There are various arrangements for road hauls connected with TOFC traffic. Where the railways use their own road vehicles in TOFC traffic they, as a rule, also handle the road haul. If the road vehicles belong to commercial hauliers or private shippers, the terminal hauls are usually carried out by the latter. In Federal Germany road hauliers are also responsible for loading and tying down the road vehicles on the railway flat cars, while in the USA and Canada these operations are performed by the railways. However, loading of the trailers is the responsibility of the road hauliers or shippers also in the USA, when they use their privately owned railway flat car and privately owned trailer.

Ordinarily, no extra cost will be incurred at terminals where suitable head or side ramps are available. Where additional terminal installations are required, they are paid for by the railways. In Germany, no such additional installations have been built. It will depend on the future development of this type of traffic whether ramps, having a height of 600 mm above top of rail will be required, when more low floor flat cars are used. No terminal installation whatever will be needed when specially designed road vehicles are employed, as in case of the Flexivan system in the USA and the Kögel-Wortmann system in Germany.

V. Tariffs.

The different countries have made various arrangements regarding the charges for transporting trailers by TOFC service.

There are standard rates but also special charges. It should be differentiated between the transport charges which the customer, or shipper, has to pay to the

railways or to the commercial road haulier and the fee which the road haulier has to pay to the railways for transporting his trailers. In Federal Germany the customer or the shipper pays for a transport by TOFC service, freight charges at the rates applicable for pure transport by road (road haul tariffs). This rule has been established, because TOFC traffic is considered as road transport moving by rail. Thus, TOFC transport provides for the shipper of a consignment, so far as freight charges are concerned neither advantages nor disadvantages. Where the TOFC transport is carried out by professional road hauliers the charges for transporting the road vehicle is paid by the consignor direct to the road haulier. The road hauliers in turn pay to the German Federal Railway transportation charges at a special rate agreed upon between them and the railways. The only advantage granted by the railways to road hauliers concerns shipments of high valued goods, for which the road hauliers pay the railways for the rail movement charges which are lower than the total freight paid by consignors to road hauliers. The railways are charging no supplements to the normal freight for furnishing special railway cars which may be considered an additional favour extended to road hauliers.

When the railways carry out TOFC transports with their own road vehicles they compute the freight charges at the rates applied for road hauls, and take into consideration the type of commodities, the weight and the distance moved. For TOFC transportation of road vehicles belonging to commercial hauliers the special agreement provides, that for each railway flat car of a certain length shall be paid a transportation charge staggered by distances but irrespective of the tare weight of the road vehicle and the type or amount of goods loaded. The road haulier is not required to state what type of goods are shipped. The transportation charges agreed upon between the railways and commercial road hauliers are such, that they will cover the out of pocket cost of the railways and are lower than the own cost incurred by the road haulier for transport purely by road. In order to arrive at a just rate, careful cost studies and comparisons between cost for TOFC traffic and road hauling have been made. Special conditions and reduced charges are applied for the return transport of empty road vehicles. No arrangements have been made regarding the fare to be paid by the drivers of the road vehicles, since the road vehicles are transported by TOFC service without the drivers. The agreements entered into between the railways and road hauliers further provide, that no goods shall be transported by TOFC which in the past have been carried by rail. In addition, road hauliers are required to deposite with the railways their license for pure road hauling. No tariffs exist for international TOFC transports, but a special agreement regarding TOFC traffic is in force between Germany and France.

The rates or special charges applied in the USA vary with the different systems used in that country. The various forms of TOFC service are :

Plan I. — Rail transportation of trailers owned by motor common carriers. Truckers solicit and bill freight at truck rates. The truckers pay the railway — either a « division » or a flat charge per trailer.

Plan II. — Trailers belonging to the railways are moved by rail. The railways deal directly with the shipper, soliciting business at railway truck-competitive tariffs.

Plan III. — The shipper provides its own trailer, owning or leasing as he wishes. The shippers deliver loaded trailers to the railway loading point. The railway puts them aboard flat cars, ties them down, moves them to destination and grounds them. The shipper handles delivery. Rates are based on commodity and quantity moved or on a flat basis.

Plan IV. — Rail movement of trailers on railway flat cars both privately owned

by the shipper. The shipper takes the trailers to the railway loading points, loads and unloads them on or off railway cars. The railway performs origin to destination movement only. Rates are based on flat charge per car, whether trailers are loaded or empty.

Plan V. — Joint rail-truck rates. In effect, such rates extend the territory of each carrier into that served by the other, permitting each to handle shipments originating in or destined to the other's territory. Each may sell for the other.

The South African Railways charge for goods conveyed in container-trailers loaded on railway flat cars the normal freight for such goods plus a percentage supplement and double cartage fees. In computing the charges for the rail movement the tare weight of the container-trailer used is disregarded. Compilation of *Table V* to show, as originally intended, the various operations to be considered in establishing a tariff has not been possible, since the data supplied by the railways concerned are not sufficient.

VI. Conclusions.

Table V shows the results of TOFC services in the USA, Canada, and Federal Germany. For Federal Germany, a differentiation has been made between the employment of road vehicles owned by the railways and the common hauliers respectively and the combined rail-road vehicles.

From this table it will be noted, that the USA and Canada range far in front. Currently, there are more than 50 American Railways operating TOFC traffic, who have entered into formal agreement. They operate about 84 % of the total mileage of the USA class I railways who are members of the Association of American Railroads. In Canada, the railways, having a similar service and membership in the Association of American Railroads, are operating approximately 80 % of the total Canadian Railway network. For the first 6 months of 1959 compared to the like period in 1958, there has been a 62 % increase in TOFC loadings. Using the number of trailers moved by rail as a basis for comparison, the increase in TOFC traffic is still greater, since a currently increasing number of railway flat cars carrying two and three trailers are employed. It is expected, that TOFC operation will become more and more standardized. The US Railways are considering the very basic problem whether to handle TOFC traffic entirely with their own organization or to use the service of independent groups such as Rail Trailer Inc. Piggy-Back Inc., etc. Fundamentally the idea on which TOFC traffic is based is considered economically sound.

With regard to Federal Germany, it may be stated, that the conditions for a fast and wide extension of the TOFC service are less favourable than in the USA and Canada since the transport distances are essentially shorter and because semi-trailers, specially suitable for TOFC traffic, are not now available in a sufficient number. The same will apply to most of the other European countries. It should be emphasized, however, that the conditions for widely extending TOFC traffic will improve considerably when, within the realm of the European Economic Community, greater traffic territories will have to be served. The governments look favourable on an extension of TOFC traffic, since it is apt to relieve the roads, and commercial hauliers also show a growing interest. Thus, the railways feel encouraged to make additional investments in rolling stock.

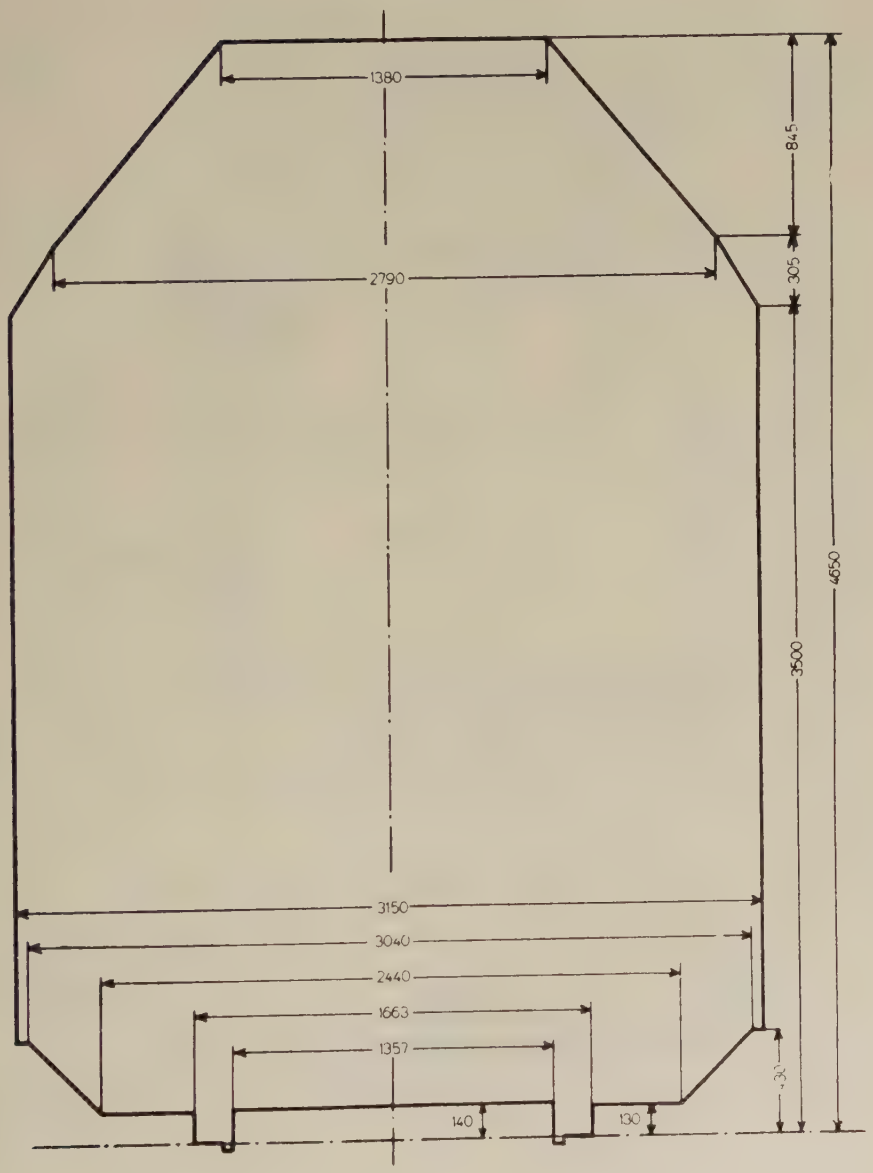
With regard to the future development of TOFC traffic, the Association of American Railroads commented :

— TOFC promises to provide a new type of transportation, that should benefit both the railways and their customers. It provides the possibility for organizing a coordinated transportation system which combines railway dependibility and economical movement by train with the flexibility of road transport.

APPENDIX 1

Federal German Republic.

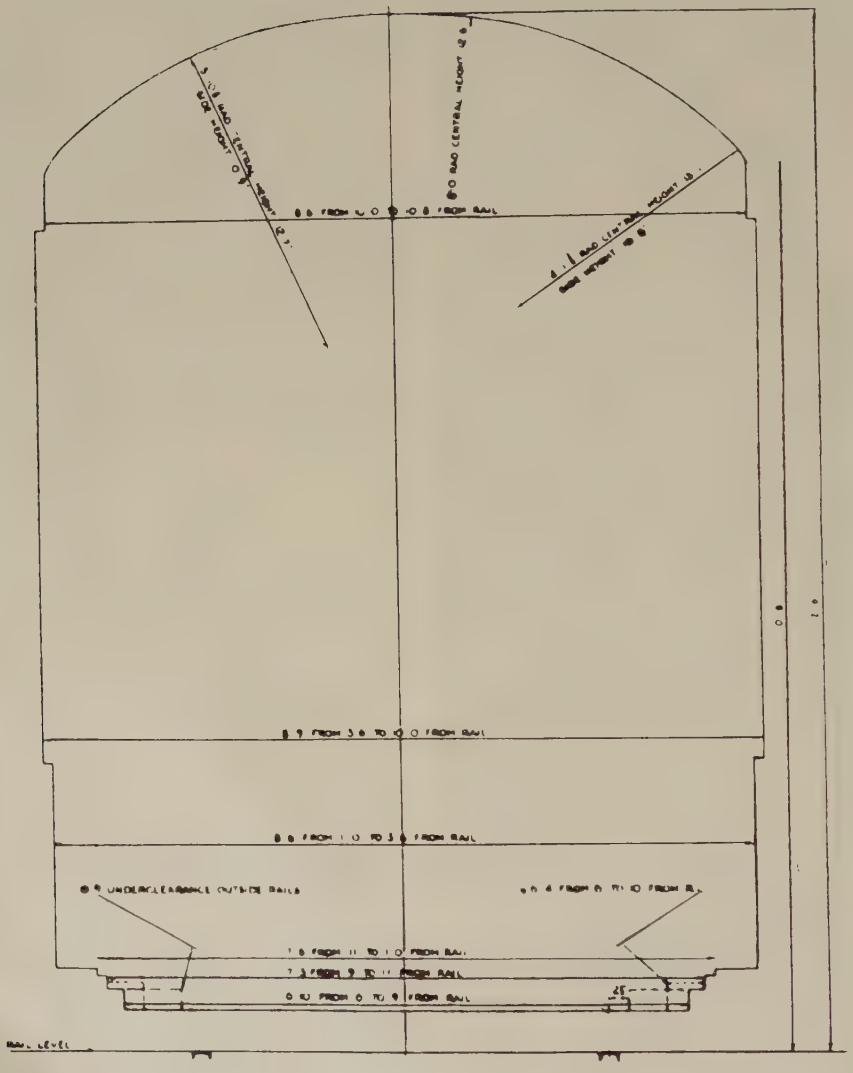
Loading gauge.



APPENDIX 2

British Railways - The Railway Executive.

Loading gauge.

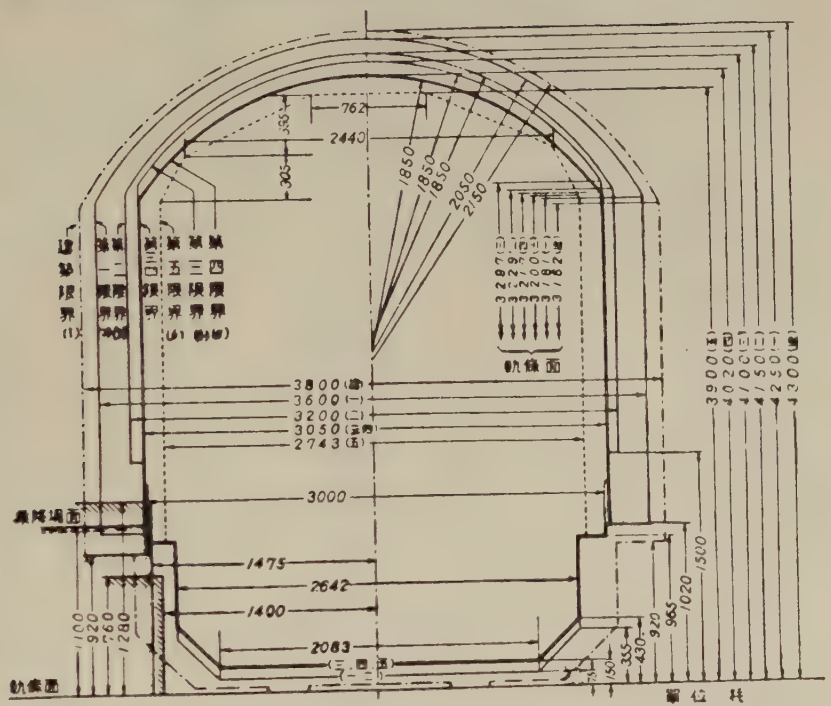


APPENDIX 3

Japan.

Loading gauge.

別表 貨物積載限界図



Platform surface

Rail surface

備考 数字は、寸法（単位ミリメートル）を示す。

Unit in mm

(1) Construction gauge.

(2) First gauge.

(3) Second gauge.

(4) Third gauge.

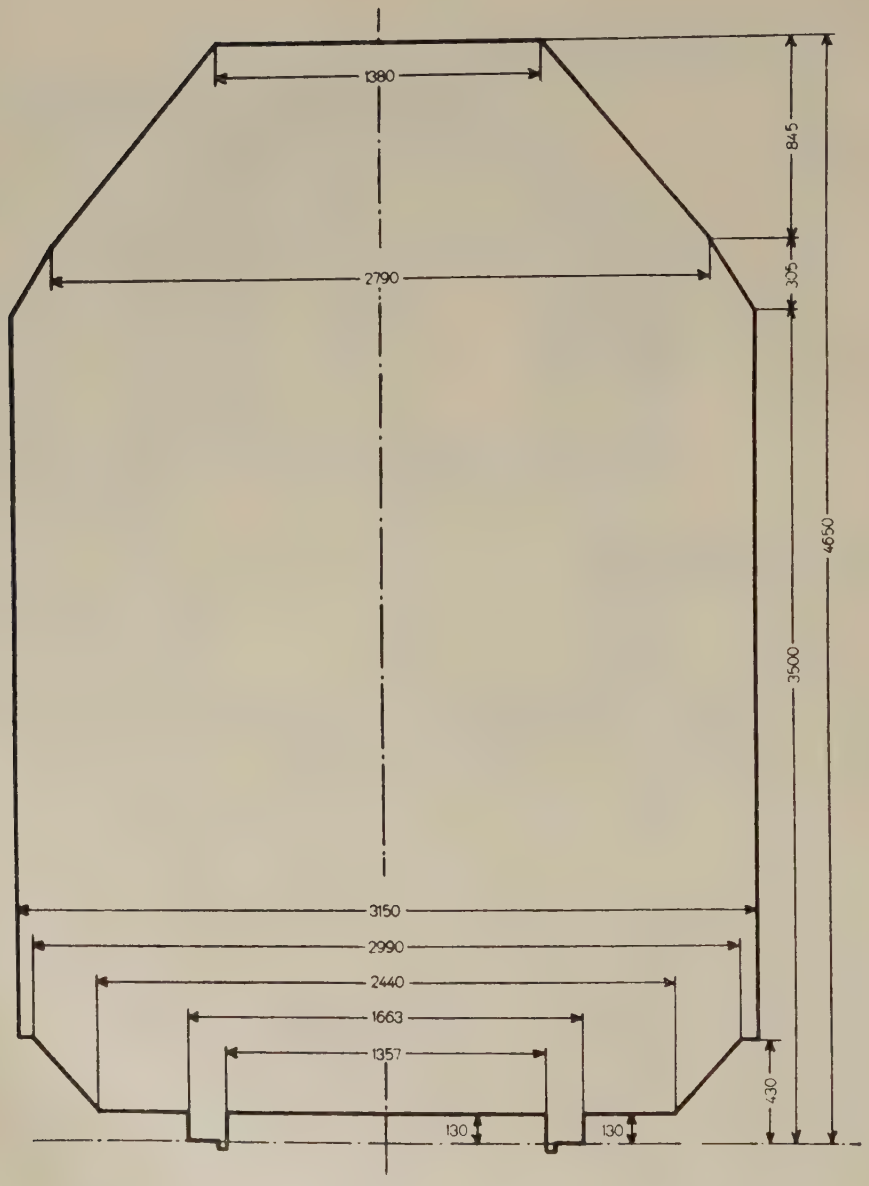
(5) Fourth gauge.

(6) Fifth gauge.

APPENDIX 4

Netherlands.

Loading gauge.



APPENDIX 5

South African Railways.

Loading gauge.

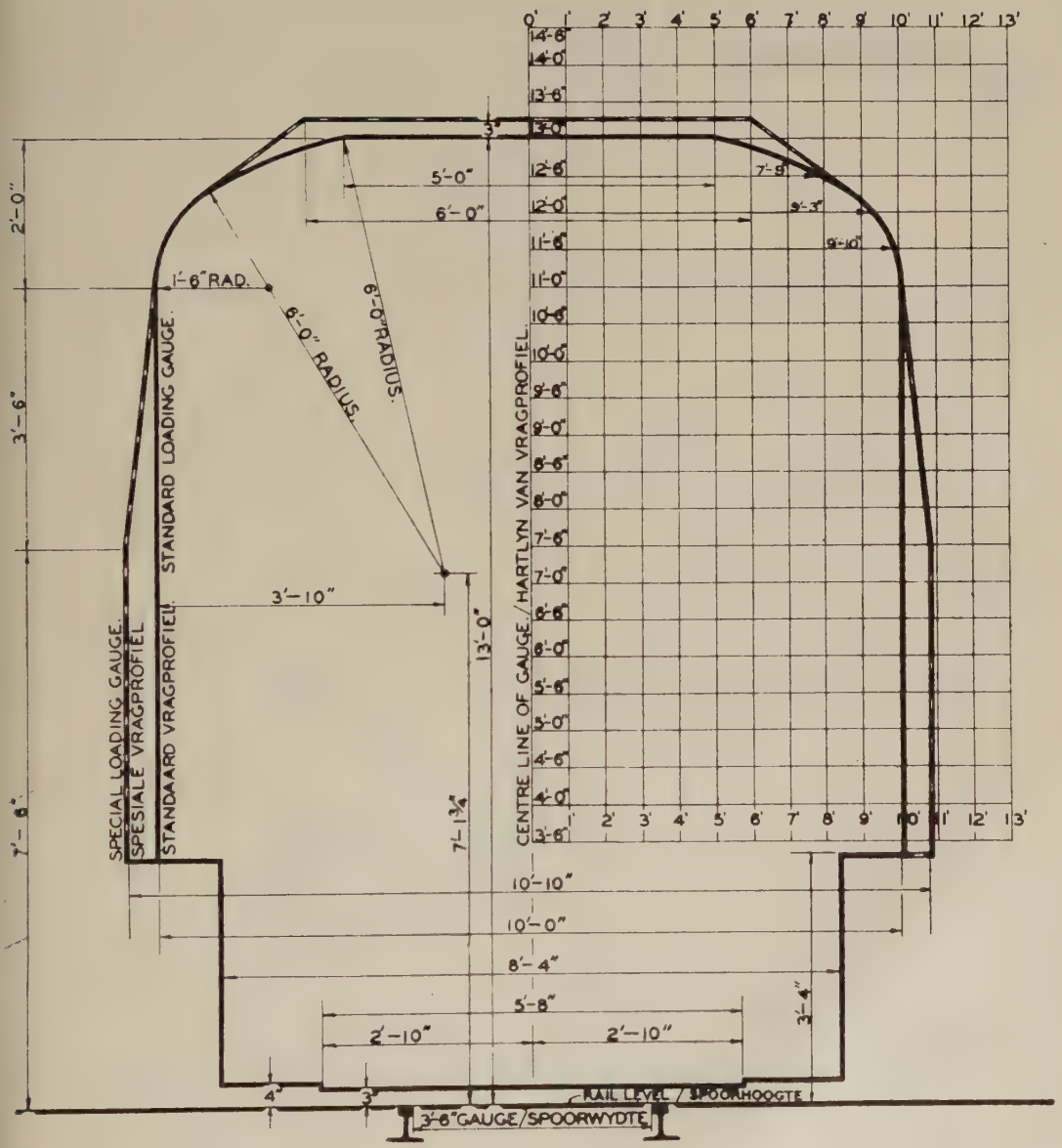


TABLE I.

Technical characteristics of road transport vehicles stipulated by legal and miscellaneous regulations.

Country	*Federal Germany*		*Netherlands*
	effective for new vehicles on 1 Jan. 58 for all vehicles on 1 July 1960	*in force until 30 June 1960*	*present status*
Total width	2.50 m	2.50 m	2.50 m
Total height	4.00 m	4.00 m	3.80 m
Total length :			
— *two axle lorries*	10 m	10 m	10 m
— *three axle lorries*	10 m	12 m	11 m
— *tractor with semi-trailer*	13 m	14 m	14 m
— *semi-trailer*	—	—	10 m
— *lorry with one trailer*	14 m	20 m	18 m
— *lorry with two trailers*	not permitted		—
Permissive axle load :			
— *for one single axle*	8 tons	10 tons	8 tons
— *for one double axle (per axle as the function of the distance between two axles)*	12 tons	16 tons	—
Permissive weight per vehicle :			
— *two axle lorry*	12 tons	16 tons	—
— *three axle lorry*	18 tons	24 tons	—
— *tractor with semi-trailer*	24 tons	35 tons	—
— *semi-trailer*	—	—	—
— *lorry with one single trailer*	24 tons	40 tons	—
— *lorry with two trailers*	not permitted		—
Size of the mud guards (if stipulated)	—	—	0.20 m
Type of coupling between tractor and semi-trailer	different systems		

TABLE I *(continued)*.

UNITED STATES OF AMERICA

STATE LEGAL MAXIMUM LIMITS OF MOTOR VEHICLE SIZES AND WEIGHTS COMPARED WITH AASHO STANDARDS

Prepared by the Bureau of Public Roads, July 1, 1956.

Line	State	Width in inches [1]	Height in ft.-in.	Length - feet [2]				Number of towed units [3]			Axle load, pounds				Gross weight limit				Specified maximum gross weight, pounds [4]						Practical maximum gross weight, pounds [5]						Line
				Single unit							Single		Tandem				Applicable to :		Truck		Truck-tractor semitrailer				Truck		Truck-tractor semitrailer				
				Truck	Bus	Truck tractor semi-trailer	Other combination	Semi-trailer	Full trailer	Semi-trailer and full trailer	Statutory limit	Including statutory enforcement tolerance	Statutory limit	Including statutory enforcement tolerance	Type of restriction	Formula or equation	Any group of axles	Total wheel base only	2-axle	3-axle	3-axle	4-axle	5-axle	Other combination	2-axle	3-axle	3-axle	4-axle	5-axle	Other combination	
1	Alabama	96	6 12-6	35	40	50	NP	1	NP	NP	18 000	19 800	35 000	39 600	Table			X							27 800	47 600	47 600	60 010	64 650	NP	1
2	Arizona	96	13-6	40	40	65	65	1	1	2	18 000		32 000		Table		Under 18′	Over 18′							26 000	40 000	44 000	58 000	72 000	76 800	2
3	Arkansas	96	13-6	35	40	50	50	1	1	NP	18 000	7 18 500	32 000	32 500	Spec. maximum [8]										26 500	40 500	45 000	59 000	65 000	65 000	3
4	California	96	13-6	35	9 35	10 60	60	NR	NR	NR	18 000		32 000		Table		Under 18′	Over 18′							26 000	40 000	44 000	58 000	72 000	76 000	4
5	Colorado	11 96	12-6	35	40	60	60	1	2	2	18 000		36 000		Formula-spec. limits	800 (L + 40)		X	30 000	46 000					26 000	44 000	44 000	62 000	76 000	76 000	5
6	Connecticut	102	12-6	45	45	45	NP	1	NP	NP	22 400	22 843	36 000	36 720	Spec. lim.-tire cap.				32 000	50 000	50 000	60 000	60 000	NP	30 848	44 720	51 000	61 200	61 200	NP	6
7	Delaware	96	6 12-6	35	42	50	60	1	1	2	20 000		36 000		Table-spec. limits [53]		X		30 000	40 000	48 000	60 000	60 000	60 000	28 000	40 000	48 000	56 350	60 000	60 000	7
8	District of Columbia	96	12-6	35	35	50	50	1	1	NP	22 000		38 000		Table		X								30 000	46 000	52 000	58 450	61 490	64 650	8
9	Florida	96	6 12-6	12 35	40	50	50	1	1	NP	20 000	22 000	40 000	44 000	Table			X							30 000	52 000	52 000	65 200	71 115	71 115	9
10	Georgia	96	13-6	13 + 39	13 + 45	48	48	1	1	NP	18 000	20 340	36 000	40 680	Spec. maximum [14]								63 280		28 340	48 680	48 680	63 280	63 280	63 280	10
11	Hawaii	96	13-0	40	40	55	65	1	1	2	24 000		30 800		Formula [55]	800 (L + 40)	Under 18′	Over 18′							32 000	38 800	56 000	62 800	69 600	78 000	11
12	Idaho	15 96	14-0	35	16 40	60	65	1	1	2	17 18 000		17 32 000		Table [17]		X								26 000	40 000	44 000	58 000	72 000	76 800	12
13	Illinois	96	13-6	42	42	50	50	1	1	2	18 18 000		32 000		Spec. lim.-tire cap.				36 000	41 000	45 000	59 000	68 000	72 000	26 000	40 000	44 000	58 000	68 000	72 000	13
14	Indiana	96	13-6	36	40	50	50	1	1	2	18 18 000	19 19 000	19 32 000	19 33 000	Spec. lim.-tire cap.[19]				72 000						27 000	41 000	45 000	59 000	73 000	73 000	14
15	Iowa	96	6 12-6	35	16 40	20 45	NP	1	NP	NP	18 000	18 540	32 000	32 960	Table		X								26 540	40 960	45 080	59 500	68 657	NP	15
16	Kansas	96	12-6	35	16 40	50	50	1	1	NP	18 000		32 000		Table		X								26 000	40 000	44 000	55 470	63 890	63 890	16
17	Kentucky	96	21 12-6	22 35	22 35	56 48	NP	1	NP	NP	18 000	57 18 900	32 000	57 33 600	Spec. lim.-tire cap.[58]				36 000	50 000	54 000	59 640	59 640	NP	26 900	41 600	45 800	59 640	59 640	NP	17
18	Louisiana	96	6 12-6	35	16 40	50	60	1	1	NP	18 000		32 000		Axle lim.-tire cap.										26 000	40 000	44 000	58 000	72 000	76 000	18
19	Maine	96	23 12-6	24 45	24 45	24 45	24 45	1	1	NP	22 000		32 000		Table-tire cap.[25]		X		32 000	50 000	50 000	50 000	50 000	50 000	30 000	40 000	50 000	50 000	50 000	50 000	19
20	Maryland	96	6 12-6	55	55	55	55	NR	NR	NR	22 400		26 40 000		Formula	850 (L + 40)		X					65 000	65 000	30 400	48 000	52 800	65 000	65 000	65 000	20
21	Massachusetts	96	NR	35	16 40	45	NP	1	NP	NP	22 400		36 000		Table-spec. limits	1 000 (L + 25)		X	27 46 000	27 60 000	27 60 000	27 60 000	27 60 000	NP	30 400	44 000	52 800	60 000	60 000	NP	21
22	Michigan	96	6 12-6	35	40	55	55	1	1	2	28 18 000		29 32 000		Axle lim.-tire cap.										26 000	30 40 000	44 000	30 58 000	30 66 000	30 102 000	22
23	Minnesota	96	6 12-6	40	40	45	45	1	1	NP	18 000		28 000		Table		X								26 000	36 000	44 000	54 000	65 500	65 500	23
24	Mississippi	96	6 12-6	35	40	59 45	45	1	1	NP	18 000		28 650	30 32 000	Table-tire cap.		X								26 000	36 650	44 000	30 54 650	30 55 980	30 55 980	24
25	Missouri	96	12-6	35	40	45	45	1	1	2	18 000		32 000		Table		X								26 000	40 000	44 000	55 470	60 010	60 010	25
26	Montana	15 96	13-6	35	40	60	60	1	1	31 2	18 000		32 000		Table		Under 18′	Over 18′							26 000	40 000	44 000	58 000	72 000	76 000	26
27	Nebraska	96	12-6	35	16 40	50	50	1	1	NP	18 000	18 900	32 000	33 600	Table		Under 22′	Over 22′							26 780	41 200	45 320	57 134	66 590	66 590	27
28	Nevada	96	NR	NR	NR	NR	NR	NR	NR	NR	18 000	18 900	32 000	33 600	Table		Under 18′	Over 18′							26 900	41 600	45 800	60 000	74 000	76 800	28
29	New Hampshire	96	13-6	35	16 40	45	45	NR	NR	NR	22 400		36 000		Table-spec. limits			X	33 400	32 47 500	52 800	66 400			30 400	44 000	52 800	66 400	66 400	66 400	29
30	New Jersey	96	13-6	35	33 35	45	34 50	1	1	NP	22 400	23 520	32 000	33 600	Spec. limits				30 000	40 000	60 000	60 000	60 000	60 000	31 500	41 600	55 040	63 000	63 000	63 000	30
31	New Mexico	35 96	13-6	40	40	65	65	1	1	2	21 600		34 320		Table		Under 18′	Over 18′							29 600	42 320	51 200	63 920	76 640	66 400	31
32	New York	96	13-0	35	36 35	50	50	1	1	NP	22 400		36 000		Formula	34 000 + 850 L		X							30 400	44 000	52 800	65 000	65 000	65 800	32
33	North Carolina	96	6 12-6	35	16 40	48	48	1	1	NP	18 000	19 000	36 000	38 000	Spec. limits				31 500	46 200	46 200	58 800	58 800	58 800	27 000	46 000	46 000	58 800	58 800	58 800	33
34	North Dakota	96	12-6	12 35	16 40	50	50	1	1	NP	18 000		30 000		Formula	650 & 750 (L+40)	Under 18′	Over 18′							26 000	38 000	44 000	56 000	63 750	63 750	34
35	Ohio	96	6 12-6	35	16 40	50	60	1	NR	NR	19 000		37 31 500		Formula	800 (L + 47.5)		X							27 000	39 500	46 000	58 500	71 000	78 000	35
36	Oklahoma	96	13-6	35	45	50	50	1	1	NP	18 000		32 000		Table		X								26 000	40 000	44 000	55 470	60 000	60 000	36
37	Oregon	96	38 12-6	35	30 40	30 55	30 60	1	1	30 2	39 18 000		39 32 000		Table [40]		Under 18′	Over 18′			72 000	76 000			26 000	40 000	44 000	58 000	72 000	76 000	37
38	Pennsylvania	96	6 12-6	35	16 40	50	50	1	1	NP	22 400	23 072	36 000	37 080	Spec. limits [41]				33 000	47 000	50 000	60 000	60 000	62 000	31 072	45 080	51 500	61 800	61 800	63 860	38
39	Puerto Rico [54]																														39
40	Rhode Island	102	12-6	40	40	50	50	1	1	NP	22 400		NS		Spec. limits				42 36 000	43 44 000	44 50 000	45 60 000	60 000	86 000	30 400	44 000	50 000	60 000	60 000	88 000	40
41	South Carolina	96	12-6	12 35	16 40	50	50	1	1	NP	20 000		32 000		Table		X								28 000	40 000	48 000	60 000	66 839	71 115	41
42	South Dakota	96	13-0	35	16 40	50	50	1	1	NP	18 000		32 000		Table		X								26 000	40 000	44 000	55 470	61 490	64 650	42
43	Tennessee	96	12-6	35	40	45	45	1	1	NP	18 000		32 000		Table			X							26 000	40 000	44 000	55 960	55 960	43 500	43
44	Texas	96	13-6	35	40	50	50	1	1	NP	18 000	18 900	32 000	33 600	Table		X								26 900	41 600	45 800	57 844	61 340	61 340	44
45	Utah	96	14-0	45	45	60	60	NR	NR	NR	18 000		33 000		Table		X								26 000	41 000	44 000	59 000	74 000	79 900	45
46	Vermont	96	12-6	50	50	50	50	1	1	NP	NS		NS		Spec. lim.-tire cap.				30 000	40 000	50 000	46 60 000	46 60 000	46 60 000	30 000	40 000	50 000	60 000	60 000	60 000	46
47	Virginia	96	6 12-6	35	30 40	50	50	1	1	NP	18 18 000		60 32 000		Table		X					30 56 800	30 56 800		26 000	40 000	44 000	56 800	56 800	56 800	47
48	Washington	96	6 12-6	35	16 40	60	60	1	1	47 2	18 000	48 18 500	32 000	48 33 000	Table-spec. lim. [49]		Under 18′	Over 18′	28 000	36 000	46 000	60 000	68 000	72 000	26 000	36 000	44 000	60 000	68 000	72 000	48
49	West Virginia	96	6 12-6	35	16 40	45	45	1	1	NP	18 000	18 900	32 000	33 600	Table		X								26 900	41 600	45 800	57 844	63 840	63 840	49
50	Wisconsin	96	6 12-6	35	40	50	50	1	1	NP	18 000	50 19 500	30 000	32 000	Table-formula [51]	1 000 (L + 26)	X								27 500	40 000	47 000	59 500	68 000	68 000	50
51	Wyoming	96	13-6	40	40	60	60	1	1	2	18 000		32 000	52 36 000	Table		X								26 000	44 000	44 000	62 000	73 000	73 000	51
	AASHO Policy	96	12-6	35	16 40	50	60	1	1	NP	18 000		32 000		Table	1 025 (L+24)–3L²	X								26 000	40 000	44 000	55 470	61 490	71 900	
Number of States	Higher	2	20	15	28	14	5	5	7	20	30		29		Formula . . . 6		18	19							29	25	29	43	34	18	
	Same	46	30	35	18	22	10	45	38	30	20		16		Table 31										21	19	21	4	2	0	
	Lower	0	0	0	4	14	35	0	5	0	0		5		Specified limits 13										0	6	0	3	14	32	

NP = not permitted. NR = not restricted. NS = not specified.

1 Various exceptions for farm and construction equipment; public utility vehicles; urban, suburban, and school buses; haulage of agricultural and forest products; at wheels of vehicles; for safety accessories, and on designated highways.
2 Various exceptions for utility vehicles and loads.
3 When not specified, limited to number possible in practical combinations within permitted length limits.
4 Legally specified or established by administrative regulation.
5 Computed under the following conditions to permit comparison on a uniform basis between States with different types of regulations
A. Front axle load of 8 000 pounds.
B. Maximum practical wheel base within applicable length limits :
(1) Minimum front overhang of 3 feet;
(2) In the case of 4-axle truck-tractor semitrailer, rear overhang computed as necessary to distribute the maximum possible uniform load on the maximum permitted length of semitrailer to the single drive-axle of the tractor and to the tandem axles of the semitrailer, within the permitted load limits of each;
(3) In the case of a combination having 5 or more axles, minimum possible combined front and, rear overhang assumed to be 5 feet, with maximum practical load on maximum permitted length of semitrailer, subject to control of loading on axle groups and on total wheelbase as applicable.
C. Including statutory enforcement tolerances as applicable.
6 Auto transports, 13 feet 6 inches.
7 Does not apply to combinations of adjacent load-carrying single axles.
8 56 000 pounds on load-carrying axles, exclusive of steering-axle load.
9 On specific routes in urban or suburban service under special permit from P.U.C., 40 feet.
10 Limited by 40-foot maximum length of similar to 55-foot practical maximum length in combination.
11 Buses, 102 inches.
12 Three-axle vehicles, 40 feet.
13 Truck, 39 feet 6 1/2 inches; Bus, 45 feet 2.4 inches.
14 63 280 pounds maximum, except on roads under Rural Roads Authority : 56 000 pounds maximum.
15 Buses, 102 inches, on highways of surfaced width at least 20 feet or otherwise as administratively authorized.
16 Less than 3 axles, 35 feet.
17 Special limits for vehicles hauling timber and timber products, ores, concentrates, aggregates, and agricultural products including livestock : single axle 18 900 pounds, tandem axle 37 800 pounds; gross weight table : vehicle with 3 or 4 axles permitted 56 000 pounds maximum at 21-foot axle spacing, vehicle with 5 or more axles permitted 79 000 pounds maximum at 43-foot axle spacing.
18 On designated highways; 16 000 pounds on other higways.
19 On designated highways, single axle 22 400 pounds, tandem axle 36 000 pounds; tolerance of 1 000 pounds on total of all excesses of weight under one or more limitations of axle load and gross weight.
20 Auto transports with load permitted overall length of 47 feet under annual permit.
21 On designated highways; 11 feet 6 inches on other highways.
22 On designated highways; trucks 26.5 feet and buses 30 feet on other highways.
23 Including load 14 feet.
24 Including load 46 feet 6 inches.
25 Trucks hauling forest products, brakes on 3 axles at 18-foot minimum spacing 48 000 pounds; trucks hauling construction materials, brakes on 3 axles at 16-foot minimum spacing 48 000 pounds.
26 Spaced less than 48 inches 36 000 pounds.
27 Subject to axle and tabular limits.
28 Single axle spaced less than 9 feet from nearest axle limited to 13 000 pounds.
29 On designated highways only and limited to one tandem axle in combination; otherwise 26 000 pounds.
30 On designated highways only.
31 Semitrailer and semitrailer converted to full trailer by means of a dolly.
32 Dual-drive axles; otherwise 40 000 pounds.
33 Or as prescribed by P.U.C.
34 Exception for poles, pilings, structural units, etc., permitted 70 feet.
35 On designated highways, 102 inches.
36 Trackless trolleys and 3-axle buses, 40 feet.
37 Spaces less than 4 feet 24 000 pounds.
38 Certain types of vehicles and commodities under special permit on designated highways up to 13 feet 6 inches.
39 Logging vehicles permitted 3-foot wheelbase tolerance, 19 000-pound single axle, 34 000-pound tandem axle
40 Governs gross weight permitted on highways designated by resolution of State highway commission.
41 Single unit truck with 4 axles permitted 60 000 pounds.
42 Axles spaced less than 6 feet 32 000 pounds; less than 12 feet 36 000 pounds; 12 feet or more gross weight governed by axle limit.
43 Single vehicle with 3 or more axles spaced less than 10 feet 40 000 pounds, less than 20 feet 44 000 pounds; 20 feet or more governed by axle limit.
44 Tractor semitrailer with 3 or more axles spaced less than 22 feet 46 000 pounds; not less than 27 feet 50 000 pounds.
45 Axles spaced 27 feet or more.
46 Tandem axles on trailer equipped with adequate brakes.
47 Under State highway commission rules.
48 Within discretion of enforcement officer.
49 Vehicles hauling logs permitted wheelbase and gross weight tolerances. Discretionary enforcement tolerances not included in computation of practcial maximum gross weights.
50 Axle load 21 000 pounds on 2-axle trucks hauling unmanufactured forest products.
51 On Class A highways.
52 Based on ruling of Attorney General.
53 Legal limit 60 000 pounds.
54 Withheld pending approval of new statutes.
55 700 (L + 40), under 18'-800 (L+40) 18 feet and over 900 (L+40) on highways having no structure with span of 20 feet or over.
56 Class AA highways; 45 feet on other highways.
57 Class AA highways only.
58 Maximum gross weight on Class A highways 42 000 pounds; on Class B highways 30 000 pounds.
59 Auto transports permitted 50 feet.
60 Vehicles registered before July 1, 1956 permitted limits in effect January 1, 1956 for life of vehicle.

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TABLE I (*continued*).

Great Britain.

Restrictions on the dimensions of road vehicles are imposed by the « Motor Vehicles (Construction and Use) Regulations », which have the force of law.

Maximum overall length.

Articulated vehicles	35 feet
Other freight vehicles	30 feet
Trailers	22 feet

Maximum overall width.

Locomotives	9 feet
Motor tractors	7 feet 6 inches
Heavy motor cars	7 feet 6 inches
Trailers	9 feet 6 inches

Maximum overall height.

There is no statutory restriction, but loads must be limited in height according to railway bridges, etc., under which they might have to pass.

Maximum loading weight.

Locomotives :	
— over 6 wheels	30 tons
— 6 wheels	26 tons
— under 6 wheels	22 tons
Heavy motor cars :	
— over 6 wheels	24 tons
— 6 wheels	20 tons
— under 6 wheels	14 tons
Trailers drawn by locomotives	40 tons
Other trailers, not articulated :	
— under 6 wheels	14 tons
Articulated vehicles :	
— trailers with four wheels and over	24 tons
— trailers with less than four wheels	20 tons

Maximum axle load.

Locomotives	11 tons
Heavy motor cars	9 tons
Trailers	9 tons

TABLE II.

Composition of the total stock of lorries.

a) *Federal Germany* : Position as on 1 June 1958.

Vehicle types					*Total number*
Lorries (pay load in tons)	3-5,9	6-7,49	7,5 and more		
Commercial hauliers	54 528	12 919	10 692		78 139
Traffic on own account	92 077	9 221	3 710		105 008
Total on 1 June 58	146 605	22 140	14 402		183 147
percentage increase (+) percentage decrease (—) against 1956	+ 3.3 %	+ 13,1 %	+ 29 %		
Trailers (Pay load in tons)	3-6,9	7-8,9	9-11,49	11,5 and more	
Commercial hauliers	25 067	8 638	11 854	11 299	56 858
Traffic on own account	53 840	11 125	5 832	3 319	74 116
Total on 1 June 58	78 907	19 763	17 686	14 618	130 974
percentage increase (+) percentage decrease (—) against 1956	— 7.3 %	— 4.7 %	+ 11.0 %	+ 8.4 %	
Tractors Position as on 1. July 1957.					3 231
Semi-trailers Position as of : 1 June 1958					4 884

b) *Netherlands* : Position as on 1 August 1957.

	Pay load in kilograms					
Vehicle types	*3001-6000 Number*	*6001-8000 Number*	*8001-10000 Number*	*10001-12000 Number*	*12001 and more Number*	*Total*
Lorries	36 340	5 855	—	—	—	42 195
percentage increase (+) percentage decrease (—) as against 1956 .	+ 3 %	+ 22 %				
Trailers	2 659	1 118	650	483	345	5 255
percentage increase (+) percentage decrease (—) as against 1956 .	— 11 %	+ 16 %	+ 13 %	+ 26 %	+ 32 %	
Semi-trailers	383	572	1 315	538	1 472	4 280
percentage increase (+) percentage decrease (—) as against 1956 .	— 8 %	+ 5 %	— 7 %	+ 7 %	+ 24 %	

c) Other countries including Great Britain, the U.S.A. and Canada have not been able to furnish sufficient or any data at all.

TABLE III.

Freight traffic on rail and road 1950 to 1957.

(Tons hauled and tons-kilometres in millions).

a) Federal Germany.

	1950	*1951*	*1952*	*1953*	*1954*	*1955*	*1956*	*1957*
Total number of tons transported								
— *Railways* . . .	229.347	254.933	262.371	246.799	252.288	282.830	299.324	305.335
— *Per cent*	= 87.5	= 85.9	= 83.8	= 81.5	= 80.5	= 80.1	= 80.0	= 79.8
— *Road transp.* . .	32.900	41.800	50.600	55.900	61.125	70.443	74.866	76.917
— *Per cent*	= 12.5	= 14.1	= 16.2	= 18.5	= 19.5	= 19.9	= 20.0	= 20.2
Total . . .	262.247	296.733	312.971	302.699	313.413	353.273	374.190	380.252
Tons kilometres								
— *Railways* . . .	43 460	50 380	50 430	46 520	47 640	52 990	56 510	56 850
— *Per cent*	= 84.8	= 83.6	= 80.8	= 77.8	= 76.6	= 76.0	= 76.1	= 75.7
— *Road transp.* . .	7 800	9 900	12 000	13 300	14 580	16 700	17 700	18 200
— *Per cent*	= 15.2	= 16.4	= 19.2	= 22.2	= 23.4	= 24.0	= 23.9	= 24.3
Total . . .	51 260	60 280	62 430	59 820	62 220	69 690	74 210	75 050

b) Netherlands.

	1950-1954	*1955*	*1956*	*1957*
Road Transport :				
— *Tons hauled*		58.62	63.92	68.67
— *Tons-kilometres*	no data	2 341.3	2 707.0	3 009.4
Percentage share in overall tonnage moved :	available			
— *rail* %		22.4	21.3	18.8
— *road* %		77.6	78.7	81.2
Tons-kilometres :				
— *rail* %		50.8	47.9	43.4
— *road* %		49.2	52.1	56.6

c) Japan.

	1950	*1951*	*1952*	*1953*	*1954*	*1955*	*1956*	*1957*
Road Transport								
— *Tons hauled* . .	286.86	324.71	349.82	455.12	493.30	532.74	617.34	739.18
— *Tons-kilometres* .	3 400.0	3 900.0	4 500.0	5 900.0	6 900.0	7 500.0	8 900.0	11 100.0
Percentage share in overall tonnage hauled								
— *Rail* % . .	37	38	35	30	28	26	25	22
— *Road* % . .	63	62	65	70	72	74	75	78

TABL

GERMAN FEDERA

Types of railway carrying cars and technic

		D.B. piggy-back (semi-trailer detachable from its wheel assembly)	
		Type H 1	*Type H 2* *(Fig. 1 to 3)*
Types of trailers or containers for door-to-door traffic	1	semi-trailer with covered body	open semi-trailer, rigging with tarpaulin
Types of railway cars for tranporting containers or trailers by rail	2	standard type Rm and Rmm railway cars	standard type Rm and Rmm railway cars
Types of vehicle for transporting containers or trailers by road	3	tractor	tractor and two axle bogie (detachable)
Equipment for transhipping from rail to road and vice versa	4	body fitted with jacks, axle guiding device, hydraulic lifting gear	body fitted with jacks, axle guiding device, hydraulic lifting gear
Terminal installations required	5	side or head ramp	side ramp
Is side loading possible?	6	yes	yes
Maximum width of trailers	7	2.5 m	2.5 m
Length of trailers	8	9 m	10 m
Height in center *at sides* *above road level*	9	3.62 m 3.5 m	3.3 and 3.5 m 3.5 and 3.7 m (adjustable)
Number of axles on trailers	10	2	2
Loading surface of container or trailers	11	20.5 m^2	23.3 m^2
Loading space of containers or trailers	12	41 m^3	46 m^3
Permissive net pay load of containers or trailers	13	16 tons	17 tons
Tare weight of containers or trailers	14	9.1 tons	5.3 tons
Tare weight of running gear	15		2.6 tons

AY (D.B.)
ristics of road vehicles transported by rail

D.B. piggy-back vehicle	*D.B. combined road-rail vehicles*	
ype « Kögel-Wortmann » *(Fig. 4 and 5)*	*Type « Uerdingen »* *(Fig. 6 and 7)*	*Type « Schöttler »* *(Fig. 8 and 9)*
e large size container (open vered)	open semi-trailer with tarpaulin	open semi-trailer with tarpaulin
ard type Rm and Rmm rail-cars — latest proposal, B.T. pecial design)	is moved on its own axles	placed on special bogies
r and semi-trailer running (detachable)	tractor, rubber tyred wheels attached	tractor
fitted with rollers attached to ody, jacks fitted to under- of trailer, cable winch with pulley, electric and hydrau-ar, fork lift truck of special for lifting and transporting *mpty* container	open track; running up wedges alongside of the track, movable axle-moving device actuated by electric motor	tilting supports attached to vehicle, retractable crankaxles, hydraulic lifting gear
loading track approach	paved loading track approach	levelled loading track approach or stabling track
	no	no
10.5 m		
2	2	2
24.5 m^2	20.6 m^2	22.3 m^2
47 m^3	36.6 m^3	36.7 m^3
14.1 tons	15 tons	16 tons
3.7 tons	8.7 tons	7.2 tons
5.5 tons		

TABL

GERMAN FEDERAL

Types of railway carrying cars and technic

		D.B. piggy-back (semi-trailer detachable from its wheel assembly)				
		Type H 1		*Type H 2 (Fig. 1 to 3)*		
Tare weight of tractors	16	6 tons		6 tons		
Tare weight of traction vehicle-trailer units ready for operation on road	17	15.1 tons		13.9 tons		
Gross weight of traction vehicle-trailer units ready for operation on road (line 17 + 13)	18	31.1 tons		30.9 tons		
Net/Gross weight ratio in per cent when moving by road $\frac{\text{line 13}}{\text{line 18}} \times 100$	19	51.5 p.c.		55 p.c.		
Ratio : pay load/dead load when moving by road $\frac{\text{line 13}}{\text{line 17}}$	20	1.06		1.23		
Tare weight of the railway wagons (standard types)	21	Rms 31 12.3 tons	Rmns 33 10.3 tons	Rms 31 12.3 tons	Rmns 33 10.3 tons	R1mns 56 12.4 tons
Tare weight of the trailer or container when loaded on railway wagon	22	9.1 tons	9.1 tons	5.3 tons	5.3 tons	5.3 tons
Tare weight of the trailer or container plus tare weight of the railway wagon on which it is loaded	23	21.4 tons	19.4 tons	17.6 tons	15.6 tons	17.7 tons
Gross weight of the trailer or container when moved by rail. . . .	24	37.4 tons	35.4 tons	34.6 tons	32.6 tons	34.7 tons
Ratio : net/gross weight in per cent $\left(\frac{\text{line 13}}{\text{line 24}} \times 100\right)$ *when moving by rail*	25	42.8 p.c.	45.2 p.c.	49.1 p.c.	52.1 p.c.	49 p.c.
Ratio : pay load/ dead load $\frac{\text{line 13}}{\text{line 23}}$ *when moving by rail* . .	26	0.75	0.82	0.97	1.09	0.96

tinued).

AY (D.B.)

ristics of road vehicles transported by rail

D.B. piggy-back vehicle *ype « Kögel-Wortmann »* *(Fig. 4 and 5)*	*D.B. combined road-rail vehicles* *Type « Uerdingen »* *(Fig. 6 and 7)*	*Type « Schöttler »* *(Fig. 8 and 9)*
5.7 tons	6.3 tons	6.3 tons
14.9 tons	15 tons	13.5 tons
29 tons	30 tons	29.5 tons
52.8 p.c.	50 p.c.	54.2 p.c.
0.95	1.0	1.19
R1mns 56 12.4 tons		6.2 tons
3.7 tons	8.7 tons	7.2 tons
16.1 tons	8.7 tons	13.4 tons
30.2 tons	23.7 tons	29.4 tons
46.7 p.c.	63.5 p.c.	54.6 p.c.
0.88	1.72	1.19

APPENDIX TO TABLE IV.

Re. : Question 9.

Characteristics of railway wagons and road vehicles transported by rail.

Great Britain.

« Railvan » (a combined rail-road vehicle of special design).

USA and Canada.

1. *Characteristics of railway wagons.*

   Most of the railways use standard type freight cars converted to suit TOFC traffic. These cars have a length of from 40 to 50 feet (12.20 to 15.20 m) each carrying one trailer. Some of the railways have procured new special flat cars for TOFC traffic of 75, 85, and 88 feet (22.90, 25.90, and 26.80 m) in length on which two and more trailers may be transported (s. 8 and 32).

2. *Characteristics of road vehicles.*

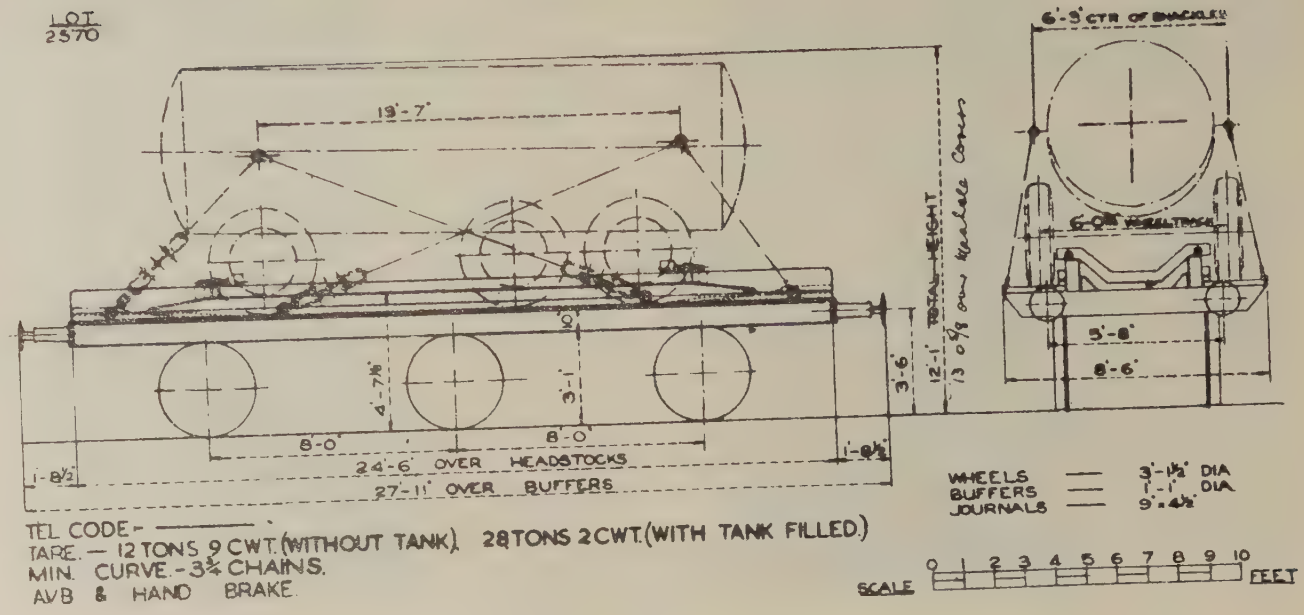
   Different types and systems are in use.

APPENDIX TO TABLE IV

Question 9

British Railways.

Chassis for road rail tank.

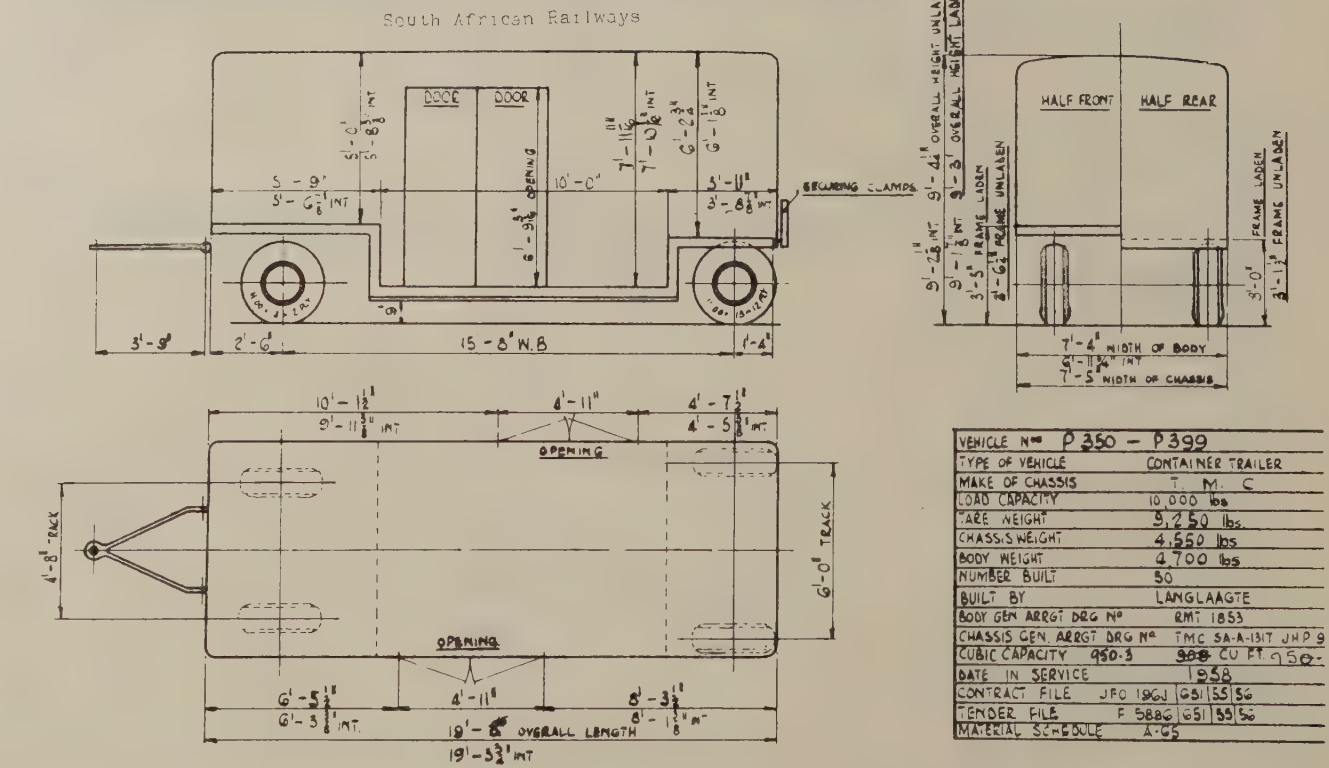


TEL CODE- ———
TARE. — 12 TONS 9 CWT. (WITHOUT TANK). 28 TONS 2 CWT. (WITH TANK FILLED.)
MIN. CURVE.- 3¾ CHAINS.
AVB & HAND BRAKE.

APPENDIX TO TABLE IV
Question 9

South African Railways.

UNLADEN WT ON FRONT AXLE	4,450	lbs	UNLADEN WT ON REAR AXLE	4,800	lbs
LADEN WT ON FRONT AXLE	9,450	lbs	LADEN WT ON REAR AXLE	9,800	lbs
LOAD ON EACH FRONT TYRE	4,725	lbs	LOAD ON EACH REAR TYRE	4,900	lbs



VEHICLE Nos	P 350 - P 399
TYPE OF VEHICLE	CONTAINER TRAILER
MAKE OF CHASSIS	T. M. C
LOAD CAPACITY	10,000 lbs
TARE WEIGHT	5,250 lbs.
CHASSIS WEIGHT	4,550 lbs
BODY WEIGHT	4,700 lbs
NUMBER BUILT	50
BUILT BY	LANGLAAGTE
BODY GEN ARRGT DRG No	RMT 1853
CHASSIS GEN. ARRGT DRG No	TMC SA-A-1311 JHP 9
CUBIC CAPACITY 950.3	~~950~~ CU FT. 950.
DATE IN SERVICE	1958
CONTRACT FILE	JFO 1960 | G51 | 55 | 56
TENDER FILE	F 5886 | G51 | 55 | 56
MATERIAL SCHEDULE	A-65

5 ton container trailer on "T.M.C." chassis (plane).

Fig. 1. — DB piggy-back tractor/trailer unit, type " Burger - v. Lienen " on the road.

Fig. 2. — DB piggy-back trailer body, " Burger - v. Lienen " loaded on railway flat car.

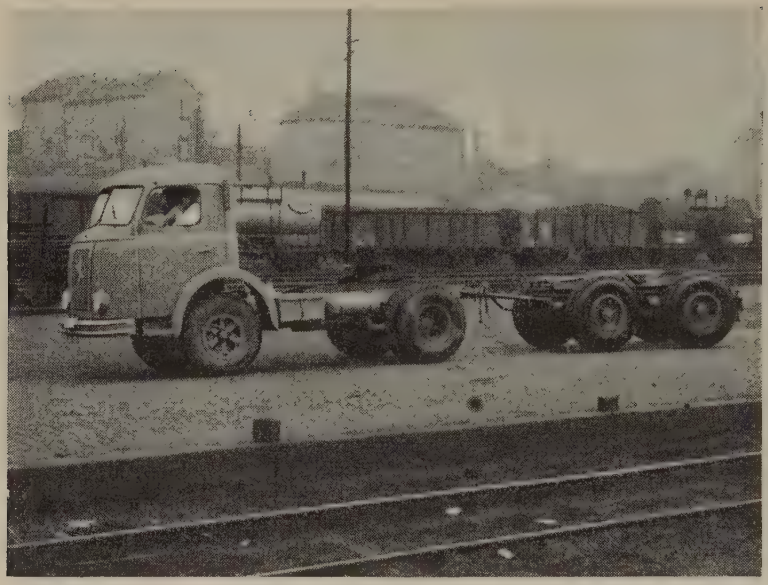


Fig. 3. — DB piggy-back tractor, type " Burger - v. Lienen " without trailer body.

Fig. 4. — Piggy-back tractor/trailer unit, type " Wortmann " on the road.

Fig. 5. — Piggy-back trailer body, type "Wortmann" being loaded on flat car.

Fig. 6. — Combined road-rail vehicle, type "Uerdingen" on the road.

Fig. 7. — Combined road-rail vehicle, type " Uerdingen " on rails.

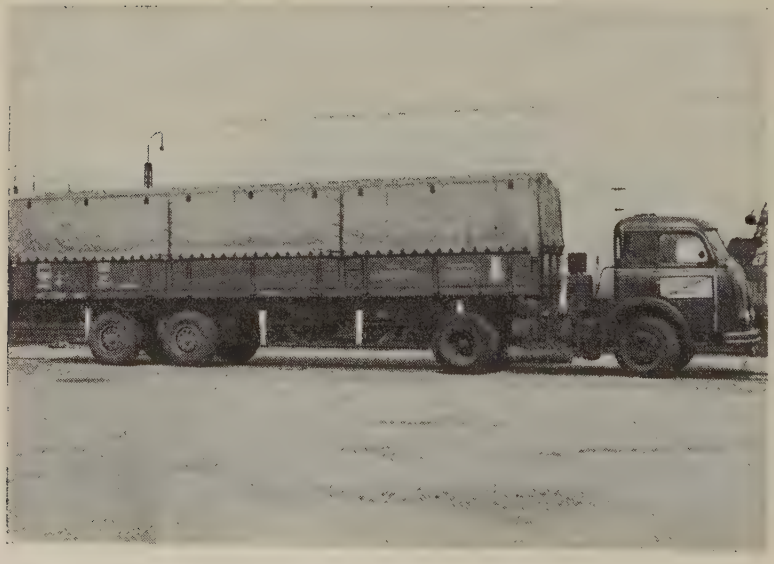


Fig. 8. — Combined road-rail vehicle, type " Schöttler-Schneider-WMD ".

Fig. 9. — Combined road-rail vehicle, type " Schöttler-Schneider-WMD " on rails.

Fig. 10.

Fig. 11.

Fig. 12.

TABLE V.

Federal Germany

German Federal Railways (DB)

Statistical records of transports on railway wagons of road-lorries and trailers loaded with goods.

	Traffic handled by the railway with own organization		*Commercial hauliers traffic*	*Traffic haudled by the railway with own combined road-rail vehicles*
	1958	*1959 Jan. to June incl.*	*1959 Jan. to June incl.*	*1959 Jan. to June incl.*
Mean distance per transport on rail	400 km	400 km	550 km	400 km
Mean distance of terminal hauls on road	20-25 km	20-25 km	—	—
Goods hauled in tons	42 542 tons	24 136 tons	5 464 tons	737 tons
Number of stations provided with facilities for combined road/rail transports (special tractors) . .	19 two each and more	19 two each and more	3 one each	3 one each
Number of lorries and trailers belonging to road hauliers transported on rail	3 743	2 128	350	66

U.S.A. AND CANADA

A.A.R. records on TOFC traffic exist since 1955 and show the following :

	1955	*1956*	*1957*	*1958*	*1959**
Participating railways . . .	32	38	40	40	50
Flat cars loaded	168 150	207 783	249 065	276 767	199 946
Peak load per week . . .	4 313	4 791	5 448	6 890	9 140

(*) 6 months January-June, inclusive.

[625 .14 (01 & 625 .144 .1]

Buckling strength of continuous welded rail,

by M. NUMATA,

Railway Track Laboratory, Railway Technical Research Institute, Japanese National Railways.

I. THEORETICAL FORMULAS OF BUCKLED TRACK

1. Assumption of buckling wave pattern.

In a continuous welded rail, constituting a long rail which is partially subjected to an axial force and as a result buckled with a wave pattern like figure 1 in the horizontal direction, the deformation, deflection angle, bending moment and shearing force at the boundary between the bend and the straight section ought to be zero, i.e. ($y = 0$; $y' = 0$; $y'' = 0$; $y''' = 0$). However, for these boundary conditions to be fullfilled, some restrictive force that is effective in the horizontal direction, like a concentrated load, is necessitated.

Strictly speaking, therefore, it would be erroneous to select from the wave patterns in figure 1 the above four items as the boundary conditions. As a matter of fact, the buckling of track is attended with fast-disappearing damping waves before and after the main wave, so the influence of the former upon the latter may be ignored as far as the energy involved with buckling is concerned.

The four sine curves satisfying these conditions will look like figure 2. Expressed in equations, they will be (1)-(4).

No. I Wave Pattern :

$$0 \leqq x \leqq l\ ; \qquad y_{11} = \frac{f}{2}\left(1 - \cos\frac{2\pi x}{l}\right) \quad \ldots\ (1)$$

No. II Wave Pattern :

$$\left.\begin{aligned} &0 \leqq x \leqq \frac{l}{3},\ \frac{2l}{3} \leqq x \leqq l\ ;\ y_{21}, y_{23} = \pm\frac{f}{2}\left(1 \mp \cos\frac{2\pi x}{l}\right) \\ &\frac{l}{3} \leqq x \leqq \frac{2l}{3};\qquad\qquad y_{22} = -f\cos\frac{3\pi x}{l} \end{aligned}\right\} \quad \ldots\ (2)$$

No. III Wave Pattern :

$$\left.\begin{aligned} &0 \leqq x \leqq \frac{l}{4},\ \frac{3l}{4} \leqq x \leqq l\ ;\ y_{31}, y_{34} = \frac{3f}{10}\left(1 - \cos\frac{4\pi x}{l}\right) \\ &\frac{l}{4} \leqq x \leqq \frac{l}{2},\ \frac{l}{2} \leqq x \leqq \frac{3l}{4};\ y_{32}, y_{33} = -\frac{f}{5}\left(1 + 4\cos\frac{4\pi x}{l}\right) \end{aligned}\right\} \quad \ldots\ (3)$$

No. IV Wave Pattern :

$$\left.\begin{aligned} &0 \leqq x \leqq \frac{l}{5},\ \frac{4l}{5} \leqq x \leqq l\ ;\ y_{41}, y_{45} = \pm\frac{3f}{10}\left(1 \mp \cos\frac{5\pi x}{l}\right) \\ &\frac{l}{5} \leqq x \leqq \frac{2l}{5},\ \frac{3l}{5} \leqq x \leqq \frac{4l}{5};\ y_{42}, y_{44} = \mp\frac{f}{5}\left(1 \pm 4\cos\frac{5\pi x}{l}\right) \\ &\frac{2l}{5} \leqq x \leqq \frac{3l}{5};\qquad y_{43} = -f\cos\frac{5\pi x}{l} \end{aligned}\right\} \quad \ldots\ (4)$$

Since the radius of curvature for the track is extremely larger than that of buckled wave pattern, if the buckled length is equal to the arc, ordinate y_o of the arc will be,

$$y_o = \frac{(l-x)\,x}{2R} \quad \ldots\ (5)$$

So, the equations of wave pattern on the curved track may be considered equal to y_n, that is, y_{nm} of each equation, (1)-(4) is added with y_o.

$$y_n = y_{nm} + y_o \quad \ldots\ (6)$$

2. Equilibrium conditions of buckled wave pattern.

The conditions that must be met for the buckled track to return to equilibrium in the wave forms described in the

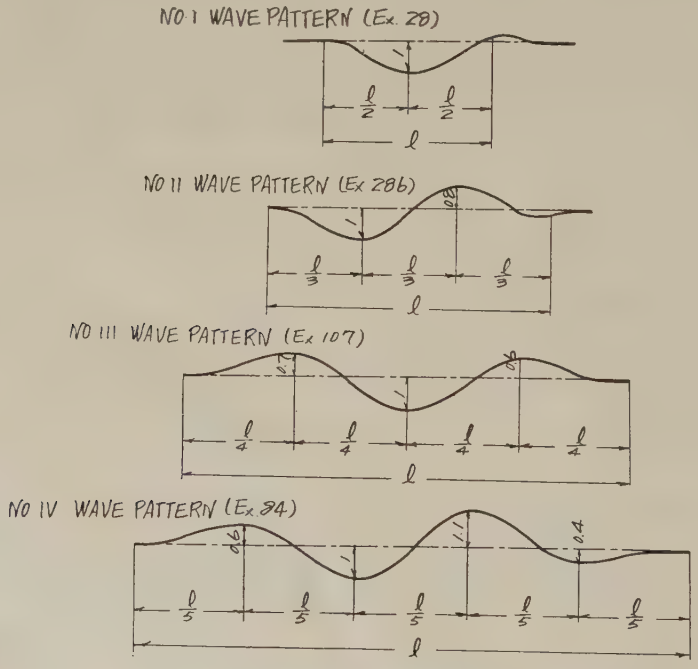


Fig. 1. — Example of buckled wave pattern in model experiment.

preceding section are sought by the Energy Method. The symbols used in the equations are as follows :

- Pt = axial force in one rail just before buckling (buckling strength) (kg);
- P = axial force of one rail in equilibrium after buckling (equilibrium axial force) (kg);
- l = length of buckled and bent track (buckling length) (cm);
- f = deflection of wave caused by buckling (buckling deformation) (cm);
- E = modulus of elasticity of rail steel (kg/cm^2);
- J = moment of inertia around vertical axis of rail (cm^4);
- A = sectional area of rail (cm^2);
- g = ballast resistance per unit length of rail on one side of track in longitudinal direction of sleeper (kg/cm);
- r = ballast resistance per unit in transverse direction (kg/cm);
- λ = difference between buckling length after bending and arc length (cm).

(1) No. I Wave Pattern :

Suppose that the track, buckled by axial force Pt and bent in No. I Wave Pattern of figure 2, comes to equilibrium under axial pressure P. Then, the equation of wave pattern will be from equations (1), (5) and (6).

$$y_1 = y_{11} + y_o = \frac{f}{2}\left(1 - \cos\frac{2\pi x}{l}\right) + \frac{(l-x)\,x}{2R}$$

Expressing by λ :

$$\lambda = \frac{1}{2}\int_o^l \sqrt{1 + \left(\frac{dy_1}{dx}\right)^2}\,dx - l = \frac{\pi^2 f^2}{4l} + \frac{fl}{2R} \qquad \ldots\ldots (7)$$

Next, with the equilibrium in the sections other than the buckled section taken into account, the relation as indicated in figure 3 will be observed.

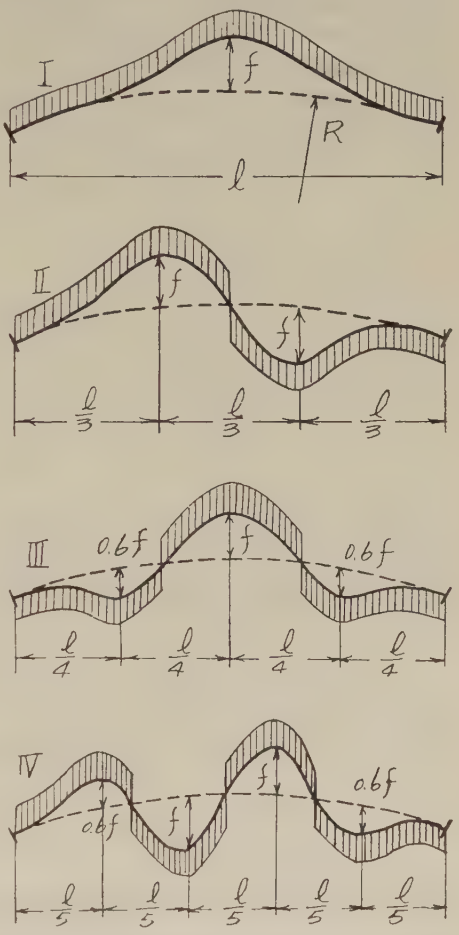


Fig. 2. — Theoretical buckled wave pattern.

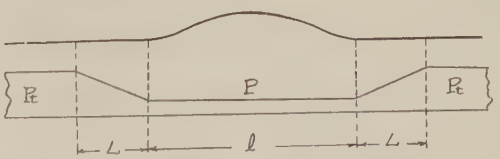


Fig. 3. — Equilibrium in rail of infinite length track.

The axial force in rail, once raised up to Pt, falls down to P within the buckled area and comes to equilibrium, but the difference of axial force between Pt and P linearly diminishes due to longitudinal ballast resistance r over the section of L, length outside the buckled area.

The resulting elongation ΔL will be,

$$\Delta L = \int_o^L \frac{(Pt - P)\,x}{LEA}\,dx = \frac{(Pt - P)\,L}{2\,EA}$$

Regardless of wave pattern, when the axial force declines from Pt to P, the rail in the buckled section elongates, the amount of elongation being expressed by :

$$\Delta l = \frac{(Pt - P)\,l}{EA}$$

Here the elongation ought to be equal to the difference λ between the buckled section of curve and the original curve (or straight section), hence :

$$\lambda = \Delta l + 2\,\Delta L \quad . \ . \ . \ . \ (8)$$

Substituting the preceding three equations into (8) :

$$P = Pt - \frac{EA}{l + L} \cdot \lambda \quad . \ . \ . \ . \ (9)$$

Accordingly, the strain energy consumed in the buckled area during the time the axial force lowers from Pt to P is,

$$Aa = \frac{Pt + P}{2} \cdot \lambda = \left\{Pt - \frac{EA}{2\,(l + L)} \cdot \lambda\right\} \lambda$$

In this state the external energy spent by the infinitesimal elongation $d\lambda$ of rail is,

$$\frac{\delta\,Aa}{\delta\lambda} \cdot d\lambda = \left\{Pt - \frac{EA}{l + L} \cdot \lambda\right\} d\lambda = P \cdot d\lambda \quad . \ . \ . \ (10)$$

Next, the internal energy Ab due to bending stiffness of rail that counteracts the buckling is given by,

$$Ab = \frac{1}{2}\int_o^l \frac{M^2}{EJ}\,dx = \frac{EJ}{2}\left(\frac{2f^2\pi^4}{l^3} + \frac{l}{R^2}\right)$$

From (7) :

$$f = \sqrt{\frac{l^4}{R^2\pi^4} + \frac{4\,l\lambda}{\pi^2}} - \frac{l^2}{R\pi^2} \qquad f > 0$$

Substituting this into the preceding equation,

$$Ab = \frac{\pi^4\,EJ}{l^3}\left(\frac{l^4}{R^2\pi^4} + \frac{4\,l\lambda}{\pi^2} - \frac{2\,l^2}{R\pi^2}\sqrt{\frac{l^4}{R^2\pi^4} + \frac{4\,l\lambda}{\pi^2}} + \frac{l^4}{R^2\pi^4}\right) + \frac{EJl}{2\,R^2}$$

The energy created by the infinitesimal elongation $d\lambda$ is :

$$\frac{\delta\,Ab}{\delta\lambda} \cdot d\lambda = \left(\frac{4\,\pi^2\,EJ}{l^2} - \frac{4\,EJ}{R\sqrt{\frac{l^4}{R^2\pi^4} + \frac{4\,l\lambda}{\pi^2}}}\right) d\lambda$$

The internal energy Ag of ballast resistance g counteracting the buckling is :

$$Ag = \int_o^l g y_{11}\,dx = 0.5\,gfl$$

Similarly the internal energy produced by the elongation $d\lambda$ is :

$$\frac{\delta Ag}{\delta\lambda}\cdot d\lambda = \frac{gl^2}{\pi^2\sqrt{\frac{l^4}{R^2\pi^4}+\frac{4l\lambda}{\pi^2}}}\cdot d\lambda$$

From the Principle of Least Work, the energies of the internal and the external forces created through micro-displacement $d\lambda$ must be equal to each other, that is,

$$\frac{\delta Aa}{\delta\lambda}\cdot d\lambda = \frac{\delta Ab}{\delta\lambda}\cdot d\lambda + \frac{\delta Ag}{\delta\lambda}\cdot d\lambda \quad (11)$$

Consequently,

$$P = \frac{4\pi^2 EJ}{l^2} - \frac{4EJ}{R\sqrt{\frac{l^4}{R^2\pi^4}+\frac{4l\lambda}{\pi^2}}} + \frac{gl^2}{\pi^2\sqrt{\frac{l^4}{R^2\pi^4}+\frac{4l\lambda}{\pi^2}}}$$

Substituting the value of λ into the equation above and rearranging it in reference to g,

$$g = \left(P - \frac{4\pi^2 EJ}{l^2}\right)\frac{\pi^2 f}{l^2} + \frac{P}{R} \quad (12)$$

The value of g in the above equation reaches a maximum with reference to l at a certain value of P and f and, above this maximum, buckling will no longer take place. The value of l giving the maximum of g is,

$$\frac{dg}{dl} = 0; \quad l = 2\sqrt{2}\,\pi\sqrt{\frac{EJ}{P}}$$

Putting,

$$\rho = \sqrt{\frac{P}{EJ}}$$

then,

$$\rho l = 2\sqrt{2}\,\pi = 8.8857 \quad . \quad . \quad (13)$$

That is, as equilibrium condition a specific value can be derived that is constant regardless of track, straight or curve.

(2) No. II-IV Wave Pattern :

The same is true with No. II-IV Wave Patterns.

No. II Wave Pattern :

$$g = \left(P - \frac{9\pi^2 EJ}{l^2}\right)\frac{\pi^2 f}{0.2425\,l^2}; \qquad \rho l = 3\sqrt{2}\,\pi = 13.3289 \quad (14)$$

No. III Wave Pattern :

$$g = \left(P - \frac{16\pi^2 EJ}{l^2}\right)\frac{\pi^2 f}{0.1685\,l^2} - \frac{0.1016\,P}{R}; \quad \rho l = 4\sqrt{2}\,\pi = 17.7715 \quad (15)$$

No. IV Wave Pattern :

$$g = \left(P - \frac{25\pi^2 EJ}{l^2}\right)\frac{\pi^2 f}{0.0977\,l^2}; \qquad \rho l = 5\sqrt{2}\,\pi = 22.2145 \quad (16)$$

TABLE 1. — **Constants of theoretical formulas.**

Wave	n	$\varkappa$	η	β	ρl	μ	φ	ξ	Remarks
I	1	0.2500	0.5000	1.000	8.8857	8.8857	17.7714	1.0000	Curve, straight
II	2	1.1250	0	0.2425	13.3289	7.9367	0	0	Straight only
III	3	1.4600	— 0.5000	0.1685	17.7715	11.7867	—	— 0.1016	Straight only
IV	4	3.0750	0	0.0977	22.2145	16.3004	0	0	Straight only

(3) General presentation of various constants :

From the above results, λ and f can be expressed by a general formula common to all the patterns.

$$\lambda = \varkappa \cdot \frac{\pi^2 f^2}{l} + \eta \cdot \frac{fl}{R} \quad . \ . \ . \quad (17)$$

$$f = \frac{\beta \cdot l^2 \left(g - \xi \cdot \dfrac{P}{R}\right)}{\pi^2 \left\{P - \dfrac{(n+1)^2 \pi^2 EJ}{l^2}\right\}} \quad (18)$$

Where the value of n, $\varkappa$, η, β and ξ are listed in Table 1. Substituting (18) for f in (17),

$$\lambda = \varkappa\beta^2\rho l\,(n+1)^2 \cdot \frac{8\,EJ\left(g - \xi\dfrac{P}{R}\right)^2}{P^3\sqrt{\dfrac{P}{EJ}}} + \eta\beta\rho l\ (n+1)^2 \cdot \frac{4\,EJ\left(g - \xi\dfrac{P}{R}\right)}{RP^2\sqrt{\dfrac{P}{EJ}}}$$

Putting: $\varkappa\beta^2\rho l\,(n+1)^2 = \mu$
and : $\varkappa\beta\rho l\ (n+1)^2 = \varphi$

$$\left.\begin{aligned} \lambda &= \mu \cdot \frac{8\,EJ\left(g - \xi\dfrac{P}{R}\right)^2}{P^3\sqrt{\dfrac{P}{EJ}}} \\ &+ \varphi \cdot \frac{4\,EJ\left(g - \xi\dfrac{P}{R}\right)}{RP^2\sqrt{\dfrac{P}{EJ}}} \end{aligned}\right\} \quad (19)$$

3. Before-and-after balancing of buckling wave pattern and buckling strength.

In figure 3,

$$L = \frac{Pt - P}{r}$$

Hence, ΔL in the preceding section is :

$$\Delta L = \frac{(Pt - P)\,L}{2\,EA} = \frac{(Pt - P)^2}{2\,rEA} \quad (20)$$

And, if a specific value, $\rho l = (n+1)\sqrt{2}\pi$ is considered for Δl :

$$\Delta l = \frac{(n+1)\sqrt{2}\,\pi\,(Pt - P)}{EA\sqrt{\dfrac{P}{EJ}}} \quad (21)$$

Then substituting (19), (20) and (21) into (8),

$$\mu \cdot \frac{8\,EJ\left(g-\xi\frac{P}{R}\right)^2}{P^3\sqrt{\frac{P}{EJ}}} + \varphi \cdot \frac{4\,EJ\left(g-\xi\frac{P}{R}\right)}{RP^2\sqrt{\frac{P}{EJ}}} = \frac{(Pt-P)^2}{rEA} + \frac{(n+1)\sqrt{2}\,\pi\,(Pt-P)}{EA\sqrt{\frac{P}{EJ}}}$$

When arranged as to Pt,

$$Pt = P + \sqrt{\frac{\gamma^2 r^2}{P} + \frac{\alpha r}{P^3\sqrt{P}}\left\{\left(g-\xi\frac{P}{R}\right)^2 + k\left(g-\xi\frac{P}{R}\right)\frac{P}{R}\right\}} - \frac{\gamma r}{\sqrt{P}} \qquad (22)$$

where

$$\gamma = \frac{(n+1)\sqrt{2}\,\pi\sqrt{EJ}}{2}$$

$$\alpha = 8\,\mu\,E^2\,JA\sqrt{EJ}$$

$$k = \varphi/2\,\mu$$

As seen from (22), the buckling strength Pt has a minimum limit, than which a smaller axial force can cause no buckling.

The extreme buckling strength Pt of the curved track is from (12) and (9).

$$Pt = \frac{4\pi^2 EJ}{l^2} - \frac{4\,EJ}{R\sqrt{\frac{l^4}{R^2\pi^4} + \frac{4l\lambda}{\pi^2}}} + \frac{gl^2}{\pi^2\sqrt{\frac{l^4}{R^2\pi^4} + \frac{4l\lambda}{\pi^2}}} + \frac{EA}{l+L}\cdot\lambda$$

when $g = \frac{P}{R}$, putting $g = \frac{P}{R}$ and $r \neq 0$ in (22), $Pt = P$. From (9), $\lambda = 0$, so,

$$Pt = gR \qquad (23)$$

4. Buckling length and deformation.

From Table 1 :

$$\rho l = (n+1)\sqrt{2}\,\pi$$

where n is the number of buckling waves,

$$\rho = \sqrt{\frac{P}{EJ}}$$

P is equilibrium axial force.

Therefore, the buckling length :

$$l = (n+1)\sqrt{2}\,\pi\sqrt{\frac{P}{EJ}} \qquad (24)$$

With (24) substituted into (18), the buckling deformation :

$$f = \beta \cdot \frac{4(n+1)^2\,EJ\left(g-\xi\frac{P}{R}\right)}{P} \qquad (25)$$

Utilizing (22), (23), (24) and (25), the relationship between Pt and l and f for No. II Wave Pattern under the consideration; straight track, 50 kg/m rail, ballast resistance g = 1-10 kg/cm, r = 2 g assumed, is obtained and plotted in solid curves in figure 4.

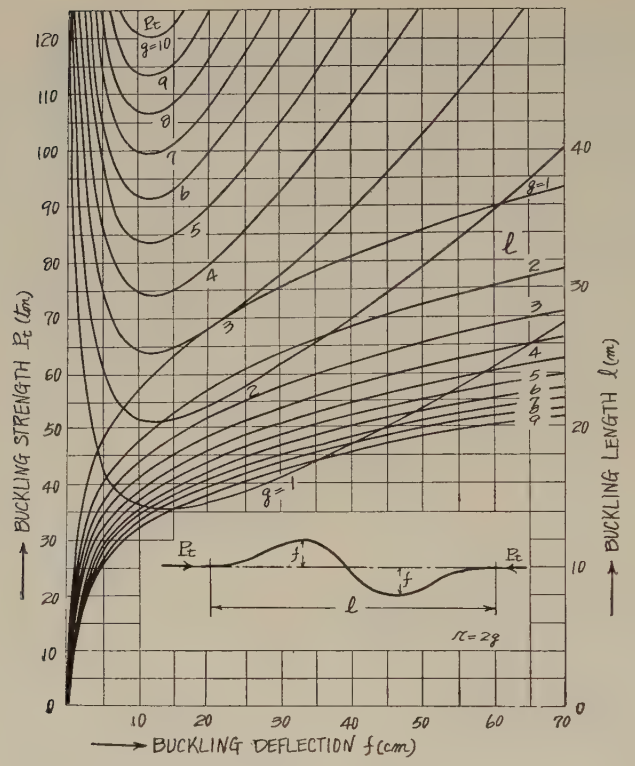


Fig. 4. — Theoretical curve (50 kg rail, No. II wave pattern).

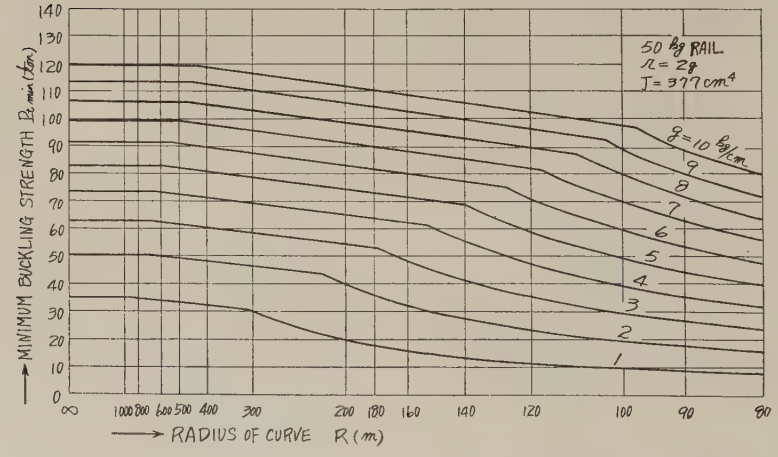


Fig. 5. — Minimum buckling strength by ballast resistance and radius of curve.

From the values of these diagrams, the minimum buckling strength for 50 kg/m rail is plotted by radius of curvature and ballast resistance in figure 5. In this case, the track skeleton stiffness is out of consideration.

5. Buckling strength of track of a finite length.

The above formulas refer to the buckling of so-called infinite length track. Under the limited considerations of a model or test track, theoretical values are bound to deviate to some extent from those based on these formulas.

In figure 6, the test track is supposed to have a length of N and $l < N < l + 2L$; and the buckling is assumed to have occurred in the middle of the track. Let both ends of the track be A and D, then the elongation ΔN of the rail in the sections AB and CD will be :

$$\Delta N = \frac{\left\{(Pt - P) - \frac{r(N-l)}{4}\right\}(N-l)}{2EA} \quad \ldots \quad (26)$$

With occurrence of buckling the points A and D shift toward the centre of track. Putting the sum of such displacement as $K(Pt - P)$, the difference λ between the curved part due to buckling and the original straight line and the elongation ΔL of rail due to the decrease in axial force in that part stand in the following relation :

$$\lambda = \Delta l + 2\Delta N + K(Pt - P) \quad (27)$$

Provided it is not so sharp a curve, the influence of the second term on the right side of (22) will be negligible.

If it is disregarded, (27) will be expressed as follows, using (20) and (26) :

$$\mu \cdot \frac{8EJ\left(g - \xi\frac{P}{R}\right)^2}{P^3\sqrt{\frac{P}{EJ}}} = \frac{(Pt - P)\,l}{EA} + \frac{\left\{(Pt - P) - \frac{r(N-l)}{4}\right\}(N-l)}{EA} + K(Pt - P)$$

Substituting (24) for l in the equation above, and arranging it, we have :

$$\left.\begin{aligned} \Phi &= \frac{8\mu E^2 JA\sqrt{EJ}}{N + EAK} & \omega &= \frac{N^2}{4(N + EAK)} \\ \delta &= \frac{(n+1)\sqrt{2}\,\pi N\sqrt{EJ}}{2(N + EAK)} & \varepsilon &= \frac{(n+1)^2\pi^2 EJ}{2(N + EAK)} \end{aligned}\right\} \quad (28)$$

then :

$$Pt = P + \frac{\Phi\left(P - \xi\frac{P}{R}\right)^2}{P^3\sqrt{P}} + r\left\{\omega - \frac{\delta}{\sqrt{P}} + \frac{\varepsilon}{P}\right\}$$

As in the case of the model experiment carried out, where the buckling length l is nearly equal to the total length N of the test rail, the following approximate formula can be obtained with $N = l$ in the above formula :

$$\left.\begin{aligned} Pt &= P + \frac{\nu\left(P - \xi\frac{P}{R}\right)^2}{\tau P^3\sqrt{P} + (n+1)\sqrt{2}\pi P^3} \\ &\text{where :} \\ \nu &= 8\,\mu\,E^2\,JA \\ \tau &= \frac{KEA}{\sqrt{EJ}} \end{aligned}\right\} \quad (29)$$

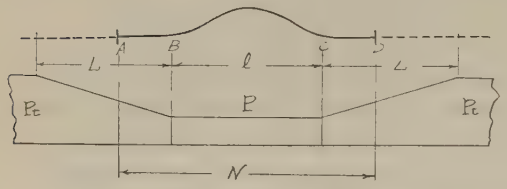


Fig. 6. — Equilibrium in rail of finite length track.

II. MODEL EXPERIMENT

1. Design of experiment.

For the purpose of checking the validity of the theoretical formulas derived in Chapter I, a large number of buckling tests have been performed on a model track.

Similarity between the model and the real rail is not always required strictly. However, in order that no particular interaction arises, a statical section of rail that is approximately similar to that of the J. N. R. 50 kg and 37 kg rail in moment of inertia has been adopted. The rail length was given 7.5 m, which was sufficient to produce the buckling length of No. IV Wave Pattern.

In the present experiment, an excessive current was directly passed through the model rail to expand it by heat, and the necessary axial force was created by the thermal stress. To hold in restraint

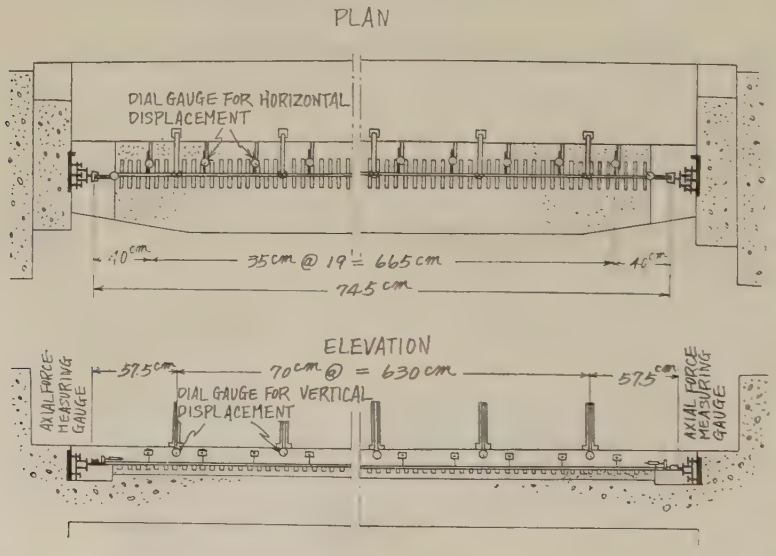


Fig. 7. — Test bank.

the model rail, in which a compressive force of 500-1 000 kg is created, both ends were anchored with a concrete block of a considerable size. The dimensions of the test bank are outlined in figure 7.

At the rail ends, there occur slight longitudinal displacements which are outward up to the moment of buckling and inward with the beginning of buckling. They need measurement for each test, for they have a bearing on the strength as displacement K, as stated in the description of the theoretical formula for the track of a finite length under Section 5, Chapter 1.

The assembled track skeleton is laid on the test bench covered with 10 mm thick sand. Parallel to the rail, 0.1 mm ⌀ piano wire is strung with 1 kg tension (centre deflection 0.61 mm). With reference to this wire, the irregularity of rail alinement, is corrected to the tolerance of $\pm$ 0.1 mm horizontally and $\pm$ 0.2 mm vertically.

The track conditions to be expected to contribute to the factors of buckling strength include the sectional area of rail, bending stiffness of track skeleton, ballast resistance and curvature of track. In the model experiment, a single rail is made to simulate in strength a whole track skeleton and the ballast resistance is given by varying the sleeper spacing. After this consideration, the following have been finally selected as experimental factors : that is, two levels of rail, three levels of ballast resistance, four levels of track curvature.

2. Main test.

The buckling test on a straight track was carried out 240 times in accordance with the programme of experiment. Figure 8 illustrates for each test the buckling strength Pt, wave pattern, buckling length l and buckling deformation f at diverse levels of ballast resistance. Figures 9 and 10 are the histograms of the buckling strength based on the measurements. In the same diagram are shown the mean

Photo 1.

value $\bar{x}$, deviation u and lower tolerance limit, of the buckling strength as calculated under the condition $1 - \alpha = 95\ \%$, $P = 0.95$.

The test on curved track was also performed 160 times. The value of Pt, wave pattern, l and f are indicated for each type of rail on figure 11. The

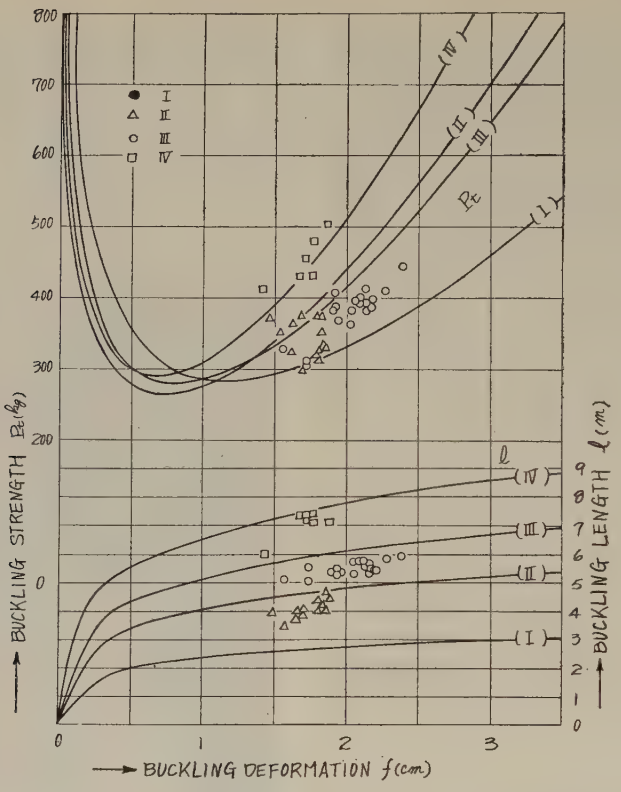


Fig. 8. — Theoretical and experimental values (straight, A-8 cm).

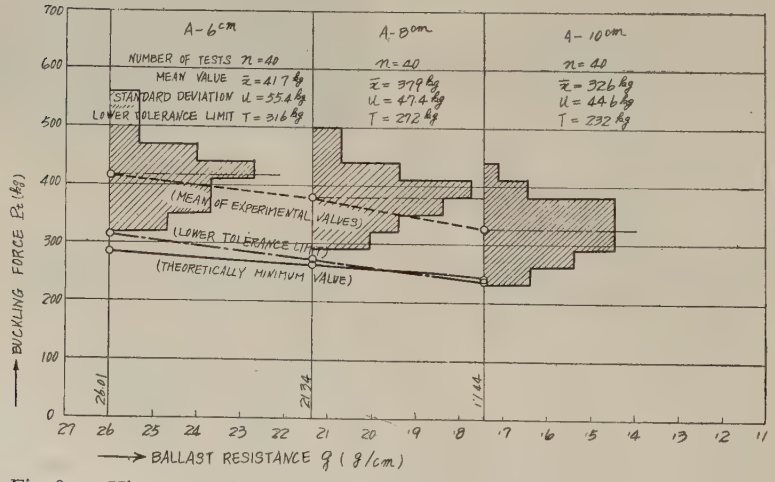


Fig. 9. — Histogram of buckling axial force in a straight track (Model rail A).

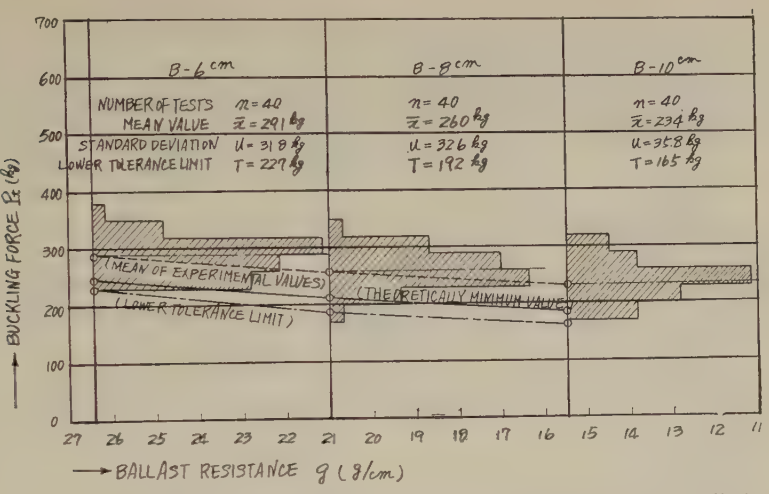

B-6 cm
B-8 cm
B-10 cm
NUMBER OF TESTS n = 40
MEAN VALUE x̄ = 291 kg
STANDARD DEVIATION u = 31.8 kg
LOWER TOLERANCE LIMIT T = 227 kg
n = 40
x̄ = 260 kg
u = 32.6 kg
T = 192 kg
n = 40
x̄ = 234 kg
u = 35.8 kg
T = 165 kg
(MEAN OF EXPERIMENTAL VALUES)
(THEORETICALLY MINIMUM VALUE)
(LOWER TOLERANCE LIMIT)
BUCKLING FORCE Pc (kg)
BALLAST RESISTANCE q (g/cm)

Fig. 10. — Histogram of buckling axial force in a straight track (Model rail B).

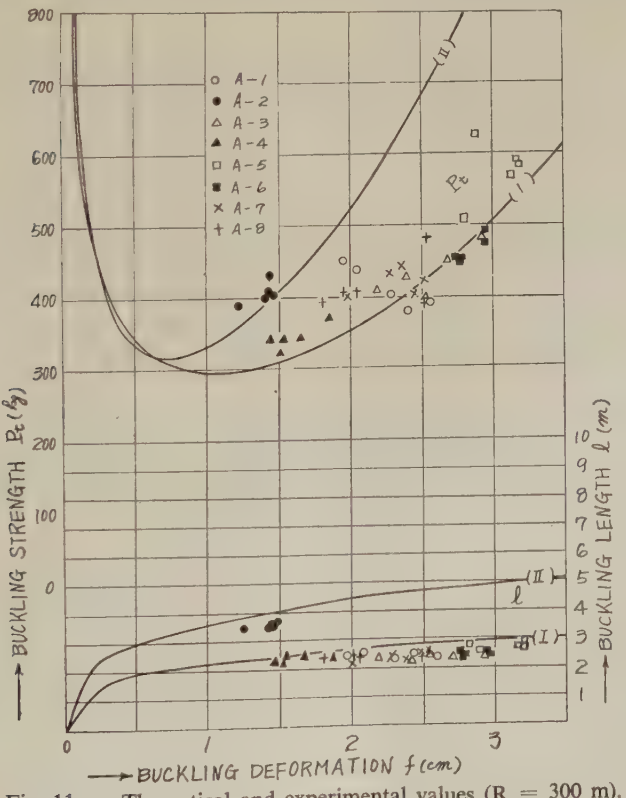


Fig. 11. — Theoretical and experimental values (R = 300 m).

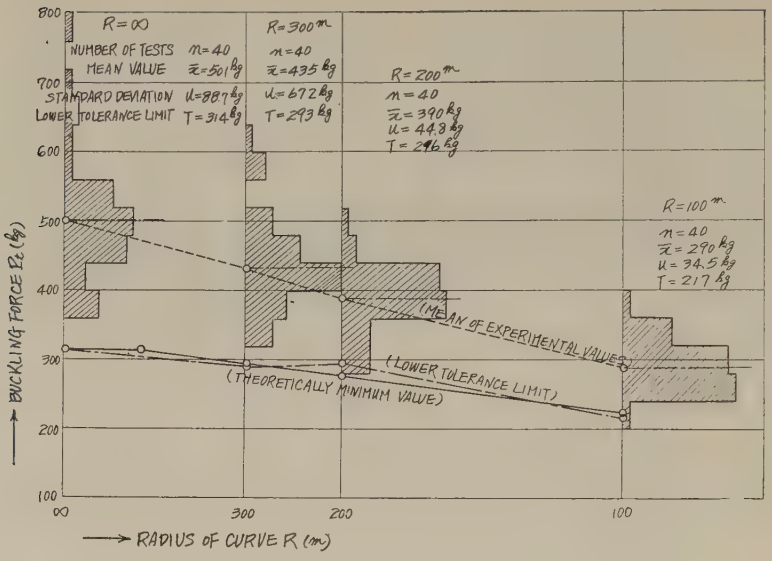


Fig. 12. — Histogram of buckling axial force in a curved track.

histogram of buckling strength is likewise given by figure 12.

3. Comparison between theoretical and experimental values.

Now comparisons are made as to No. III Wave Pattern which was most frequent in the case of straight track. Mean value of f and buckling strength Pt of this pattern are calculated. From the intersection of the two a normal line is drawn toward the theoretical curve and the foot of the normal line is taken as the theoretical value. Values of the ratio between the theoretical and the experimental value are given in Table 2, in

TABLE 2. — **Comparison between experimental and theoretical values.** *(Straight track).*

Track conditions		A-6 cm	A-8 cm	A-10 cm	B-6 cm	B-8 cm	B-10 cm
Experimental	fm (cm)	2.15	2.06	1.96	1.59	1.38	1.44
	Ptm (kg)	425	383	340	283	249	223
Theoretical	Pt (kg)	458	405	360	322	270	242
	Ptm/Pt (%)	92.5	94.5	94.5	88.0	92.1	92.1

which the latter is 7-8 % lower than the former.

The relationship between experimental and theoretical value in the case of curved track is expressed in percentage in Table 3.

generally considered practicable to the extent of 600 m radius of curvature without any particular reinforcement of track, so far as the buckling strength is concerned.

TABLE 3. — **Comparison between experimental and theoretical values.** *(Curved track).*

Radius :	∞				300 m		200 m	100 m
Wave pattern :	I	II	III	IV	I	II	I	I
Number of tests	5	14	16	5	35	5	40	40
Experimental — *fm* (cm)	2.24	1.70	1.95	1.93	2.40	1.40	2.06	1.15
Experimental — P*tm* (kg)	390	487	516	636	439	408	390	290
Base resistance neglected — Theoretical P*t* (kg)	408	472	502	620	418	400	360	235
Base resistance neglected — P*tm*/P*t* (%)	95.6	103.6	102.8	102.6	105.0	102.2	108.4	123.4
0.7 *g* assumed — Theoretical P*t* (kg)	442	492	524	640	452	418	392	258
0.7 *g* assumed — P*tm*/P*t* (%)	88.2	98.9	98.6	99.2	96.8	97.8	99.2	112.0

The theoretical formulas derived in Chapter I generally agreed with this experimental value both in the straight and in the curved track.

III. BUCKLING TEST ON REAL TRACK

1. Design of experiment.

According to the theoretical study and the model tests conducted so far by the laboratory to which the author belongs, laying of continuous welded rail is

J. N. R. planned to carry out a full scale field test on the test track installed specially for the purpose at Suita Marschalling Yard, and since June 1955, besides various basic experiments, the buckling test had been conducted 8 times.

In order to obtain the pressure on the rail, we used small fire tubes for locomotive boiler, laid along both sides of web of rail to pass the saturated steam (about 8 atm. press.) of a steam locomotive.

The purpose of the test is to check the theoretical buckling strength of a

track of 50 kg/m rail with 600 m radius. Therefore, to facilitate the comparison with theory, basic tests were conducted to obtain the ballast resistance and the stiffness of track skeleton of the test track.

2. Main test.

The test track is a newly-laid 320 m long curve with R = 600 m. To create in its middle part a uniform axial force covering a considerable length (60 m), both ends should be fairly rigidly fixed each by three of D-52 and D-51 locomotives (100-120 tons) and piles.

There was hardly any local difference in the rail temperature, so the average of the measured values at six points for inner and outer rails was adopted and from this average was sought the temperature difference from the time of installation to the moment of buckling, which was the necessary value for calculation of buckling force. As the rail is heated, the rail of buckling section develops a large axial force, under restraint of the fixed section. Actually, however, the rail extends itself though only to a small amount toward the fixed section, reducing the axial force accordingly. Therefore, in the computation of the buckling strength, just this amount of extension must be compensated. Further for the comparison with theory, it is necessary to have the amount of displacement, caused by the axial force which declines through buckling, between the two ends of the fixed section. It was measured with a dial-gauge from the standard beam (see Photo 2).

Lateral displacement of rail up to the moment of buckling and that after buckling had started were recorded automatically by the pencil on the recording paper on the cross beam. The lift of rail,

Photo 2.

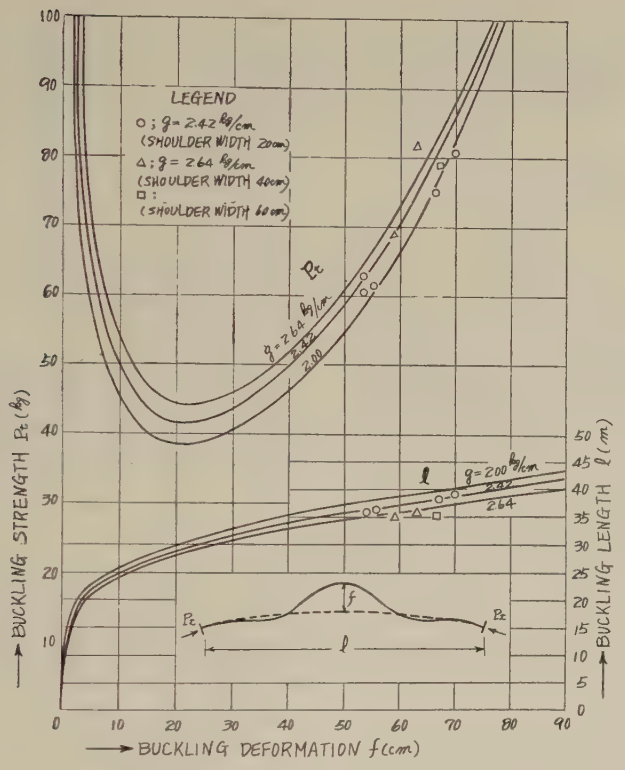


Fig. 13. — Buckling results and theoretical curve.

which was supposed to cause a loss in ballast resistance, was measured by the scale attached to the standard beam. The form of rail after buckling was determined by measuring the distances from the standard piles driven at an interval of 2 m on the formation level on the outer rail side.

The experimental values of buckling obtained from the tests on the real track are compared with the theoretical formulas in Chapter I to determine the validity of the latter. The test track is of a finite length with fixed sections on both sides and here the formulas for an infinitely long track is inapplicable. Instead of decreased section L of figure 6, it must be assumed that the buckling section has, at its ends, A and D displacements due to the resistance K (Pt — P)/2. The theoretical buckling strength Pt at the test track whose length N $\neq$ buckling length l is calculated from (28) of Section 5, Chapter I.

The relationships between Pt and f and between f and l were established, and the results were plotted in the theoretical curve of figure 13. In any case, the agreement was excellent, being 98.4-102.6 %.

[625 .1 (460)]

The Railway from Zamora to La Coruña,

by F. Moral,

Ingénieur en Chef au Secrétariat général de la Direction du Réseau National des Chemins de fer Espagnols (R.E.N.F.E.).

I. History.

Railway communications between the centre of Spain and Galicia formerly followed an itinerary via *Madrid, Palencia, León* and *Monforte* and thence on to *La Coruña*. From *Monforte*, the line went via *Orense* to *Vigo, Pontevedra* and *Santiago*.

By this route *Vigo* and *La Coruña* were respectively 837 and 845 km from *Madrid*, the line being a very difficult

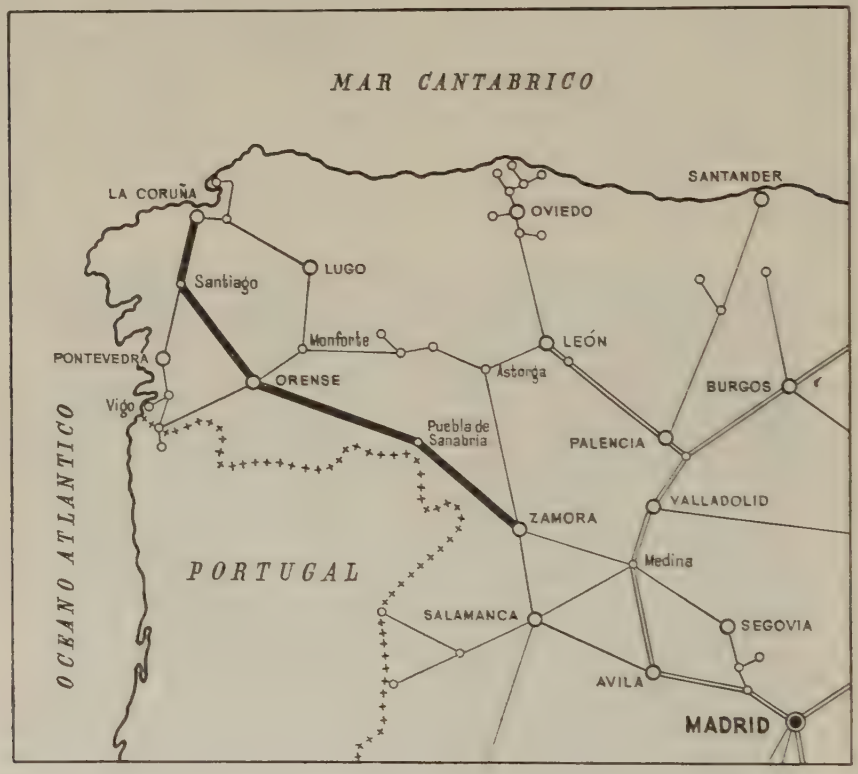


Fig. 1. — On this diagram which shows in heavy lines the layout of the new railway from Zamora to La Coruña, it can be clearly seen how much shorter the present route Madrid-Medina-Zamora-Orense is than the old route Madrid-Medina-Palencia-León-Monforte.

single track one after *León,* which greatly limited the possibilities of using these two great Atlantic Ports and also put difficulties in the way of the industrial development of Galicia. There had long been a real need to improve the railway communications by making a more direct line, linking up *Medina del Campo* via *Zamora* to *Orense* and extending over a more direct layout towards *Santiago* and as far as *La Coruña;* this would also have to make it possible to improve communications with the port of *Vigo,* which could remain linked up by its former line with the new railway at *Orense* junction and would be on a direct line to *La Coruña* via *Santiago* (fig. 1).

Once the construction of this railway had been decided upon, a beginning was made with the *Medina del Campo* to *Zamora* section. Work was temporarily brought to a standstill at this point on account of economic difficulties, but in the year 1926 the Comte DE GUADALHORCE, who was then Minister of Public Works, had work on this railway resumed at the expense of the State.

The work began in 1927, but was considerably slowed down in 1932, and then was completely paralysed because of the Civil War between 1936 and 1939. After the war, work was resumed and pushed forward actively, so well that the inauguration of the *Santiago-La Coruña* section (75 km) took place in 1943, and once all the difficulties due to shortage of materials and economic isolation had been overcome, the construction of the tunnels and viaducts was pushed on, so that in 1953 the *Zamora* to *Puebla de Sanabria* section was inaugurated, the *Puebla de Sanabria-Orense-Carballino* section in 1957 and finally the whole railway opened to traffic on the 8th September 1958.

II. The permanent way and its bed.

The line, whose total length from *Zamora* to *La Coruña* is 452.480 km reaches an altitude of 1 105 m above sea level; this is the place where there is the *Canda* tunnel, which is 2 008 m long, and consequently one of the longest on this railway.

The line is laid to the usual Spanish gauge with 12 m long rails weighing 45 kg per metre with 20 sleepers per rail length; the layout includes transition curves, and these as well as the straight sections and circular curves are checked by means of numbered reference posts which are sited 1 m from the outside rail.

The maximum gradient is 15 mm per metre and the minimum radius of curves is as low as 400 m.

The very difficult topography of the regions through which this line runs has necessitated the carrying out of numerous works, all the bridges being designed for double track. On this 452 km, it was necessary to build 14 viaducts and 182 *tunnels,* whose cumulative length is 2.70 km in the case of the viaducts and 74 km in the case of the tunnels, this latter figure representing some 16.4 % of the total mileage of the line (fig. 2). There are 14 tunnels more than 1 km long and 24 of lengths between 500 and 1 000 m.

The most important works are the

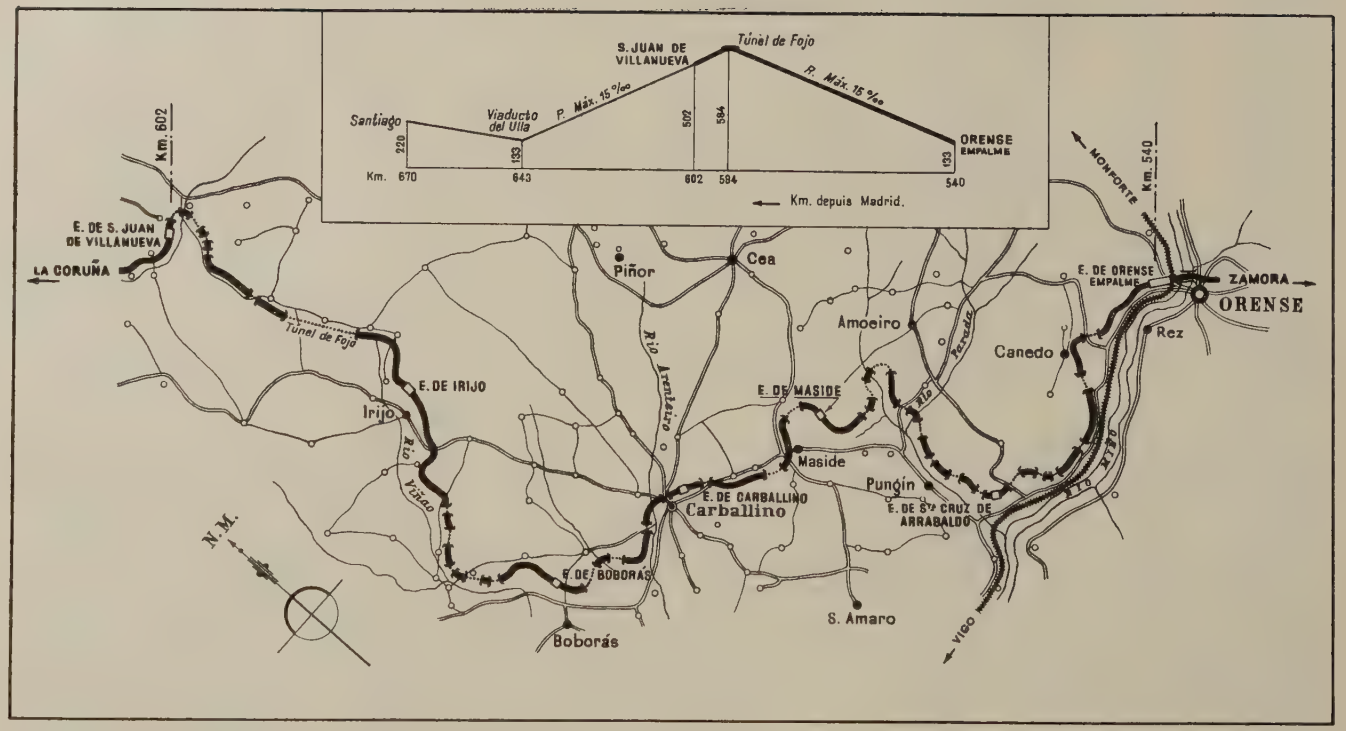


Fig. 2. — This 62 km long section beginning at Orense includes 32 tunnels, a great number of curves and a maximum gradient of 15 °/₀₀; this gives a clear idea of the difficulties encountered in its construction and operation.

THE MOST IMPORTANT VIADUCTS ON THE LINE

Name	Length in metres	Maximum height above rail level in metres
Esla	481	84
Vertillo	212	28
Truchas	280	47
Arnoya	167	48
Miño	359	45
Sixtis	160	12
Parada	71	43
Arenteiro	121	28
Agre	128	30
Deza	131	40
Toja	140	23
Ulla	219	86
Reconco	109	27
Tambre	93	13

viaduct over the *Esla* and the *Padornelo* tunnel.

The *Esla* viaduct is 481 m long and 84 m high above the river. It consists of a large central arch, in reinforced concrete built by means of an electrically welded self-supporting metal arch; it has a span of 209.84 m and 60 m rise, and is completed by 8 other arches of 22 m span (five towards *Zamora* and three towards *La Coruña*), together with two small straight spans at each end. When this viaduct was inaugurated in 1943, its central arch was the higgest in the world (fig. 3) after the 264 m arch of the *Sando* bridge in Sweden. Figures 4, 5 and 6 show other important viaducts on this line.

The *Padornelo* tunnel, 1 104 m above sea level, is 5 949 m long and at the present time is the longest tunnel in Spain, though the *La Egaña* tunnel on the *Santander-Mediterranean* Railway, which is now under construction will be 6 996 m long.

All crossings of this railway with road and other lines are by means of over or under bridges, which made it necessary to undertake considerable work on diversions.

There are altogether 52 stations on the line, many of them of great importance, such as those of *La Coruña, Santiago, Orense,* and *Zamora,* which were designed so that they are large enough to take the longest trains. The buildings have been inspired by the idea of amalgamating a rational functional design with rational aesthetics based on the local architecture (fig. 7, 8 and 9).

III. Signalling, telecommunications and electric power.

Between *Zamora* and *Puebla de Sanabria* (inclusive), all the signal boxes are

TUNNELS MORE THAN 500 M LONG

Name	No.	Distance from Madrid	Length in metres	Altitude in metres
Paradas	11	408	1 232	1 014
Teixidelo	17	414	547	1 077
Padornelo	19	415	5 949	1 104
Lubián	21	424	1 713	1 050
Briallo	24	428	981	1 070
Canda	25	430	2 008	1 105
Cabaixes	29	445	647	1 006
Teresa	37	454	601	996
Bolaños	46	450	546	1 010
Malpaso	47	461	839	999
Fornallo	51	464	955	969
Camba I	54	467.5	1 102	942
Camba II	55	469	1 549	919
Buzagueira	58	471.5	505	890
Pereiro	61	474	1 064	868
Corno	62	475	2 471	842
Canellon	63	478	1 267	807
Sierra Pequeña	66	480.5	1 569	778
Valdecomeas	69	483	641	770
Prado	71	485	577	768
Valdemonte	82	490.5	573	719
Salgueiros	91	512	1 566	474
San Francisco	95	537	772	148
Quintela	96	542.5	572	236
Cova das Serpes	101	550.5	800	191
Faracho	105	555	516	242
Parada	106	556.5	560	261
Cervenza	107	557.5	847	289
San Fiz	108	559.5	560	305
Figueiredo	110	564	637	359
Maside	112	566.5	593	398
Astureses	117	575.5	917	442
Fojo	124	594	2 606	584
Naufe	128	600	550	510
Santiago	164	677	554	302
Vista Alegre	173	726.5	1 828	202
Bregua	175	729	843	154
Espilde	180	739.5	1 404	92

equipped with electric interlocking; the line is equipped with light signals and automatic block between stations.

Santiago and *La Coruña* stations have light signals with electric interlocking, whilst in the other stations mechanical signals and interlocking have been fitted with fixed boards giving warning of approaching signals; there are advanced signals with triangular boards, posts marking shunting limits, stop blocks, point locks and Bouré locks, two wire

cables being used for all the transmissions.

A telephone line parallel to the track makes use of a reinforced cable made up of five pairs and laid under the track in the cuttings and embankments or suspended from the walls of tunnels, near the track, with protection for the cable on entering and leaving tunnels.

This line is equipped with load coils and emergency points on the open line, with cast iron boxes having connections for auxiliary telephones. There are selective and general telephone equipments at all the stations, using two pairs of cable, another pair being used for direct calls, and the remaining two for the telephone sectioning between the stations.

A high tension line all along the track assures a supply of electricity for railway requirements, and all the stations are equipped with converter posts supplying the distribution system with low tension current to light the buildings, offices, yards, platforms and track. In some stations 25 m high metal pylons have been erected with three 1 000 W lamps to light the platforms and sidings.

Fig. 3. — Viaduct over the river Esla in the province of Zamora. The central arch in reinforced concrete has a span of 209.84 m and a rise of 60 m. The track is 84 m above the river bed.

Fig. 4. — Viaduct over the river Miño, near Orense, with a total length of 359 m and 45 m above the river bed.

Fig. 5. — Viaduct of Arnoya, 167 m long and 48 m above the river bed.

IV. **Operating.**

All the installations were provided for steam traction, but in view of the time that has elapsed between the project for the railway being first got out and the progress realised in recent years with other methods of traction, the advisability of operating with Diesel traction had to be considered, as this appeared to be more suitable for the special characteristics of the line with its steep gradients, numerous small radius curves, large number of tunnels, and in certain regions, the shortage of water, which would have made it difficult to supply the locomotives, so that steam traction would have been anti-economic.

Fig. 6. — Viaduct over the river Ulla, 219 m long and 86 m above the river bed. The centre arch in reinforced concrete, built by means of an electrically welded self-supporting metal arch has a theoretical opening of 52.80 m and a rise of 27 m.

The side arches are 10 m wide and are made of reinforced concrete.

A thorough investigation was made in 1951 into the possible advantages of using Diesel traction compared with steam traction. The conclusion was that the cost of Diesel traction per kilometre would be 48 % lower than that

of steam traction for the freight services and about 35 % lower for the passenger services; it was found in addition that the number of locomotives needed could be reduced by half.

When the *Puebla de Sanabria-Orense-Carballino* section was put into service in 1957, the railway had no Diesel locomotives; this was why the Traction Department had to decide to make use of steam traction for the time being, whilst having to cope with the difficulties that ensued owing to the great number of tunnels and steep gradients on this section, which often gave rise to serious traffic troubles. These difficulties are disappearing as the steam locomotives are being replaced by Diesel locomotives, which now already assure the greater part of the passenger and freight services.

ALCO Diesel-electric locomotives of 1 800 HP are used on this line with four stroke engines, 12 cylinders in Vee and 1 000 r.p.m. (fig. 10).

They have two three axled bogies and three traction motors each. The weight of the locomotive in running order is 108 t with a maximum speed of

Fig. 7. — Santiago de Compostela station. Booking office and metal roof over the platforms. This building is one of the finest railway buildings, and reflects the classic architecture of the region.

On the right a metal pylon for lighting by reflectors.

105 km/h and a tractive effort of 20 820 kg. The diameter of the wheels is 40″; they are fitted with a dynamic brake and an automatic compressed air brake.

The RENFE now has 24 locomotives of this type, which work the services between *Orense-Zamora, Orense-Coruña, Orense-Vigo* and *Ponferrada-Monforte-Orense.*

simultaneously; in addition it is being equipped with all the installations needed for storing and fuelling with Diesel oil.

V. **Repercussions on the national economy.**

The new line runs through the provinces of *Zamora, Orense, Pontevedra* and *La Coruña,* which are very rich forestry, agricultural and mining districts,

Fig. 8. — Booking office of Orense-San Francisco Station, showing the beauty of line and proportion native to the architecture of Galicia.

To deal with the maintenance and repair of these Diesel locomotives, the *Orense* steam locomotive depot is now being turned into a Workshop-Depot for Diesel traction, with raised platforms and inspection pits so that it will be possible to work on three different levels

well known for their stock raising as well as their deposits of wolfram, iron, tin and lithium. The railway will contribute to the rapid industrial development of this region, where it is proposed to set up new industries in order to profit by its natural wealth.

Fig. 9. — Orense Junction Station, where the new railway line links up with the old line from Monforte to Vigo.

In the centre will be seen the booking office and the concrete roofs over the passenger platforms.

Fig. 10. — ALCO 1 800 HP Diesel-electric locomotive.

Weight in service : 108 t.
Maximum speed : 105 km/h.
Tractive effort : 20 820 kg.

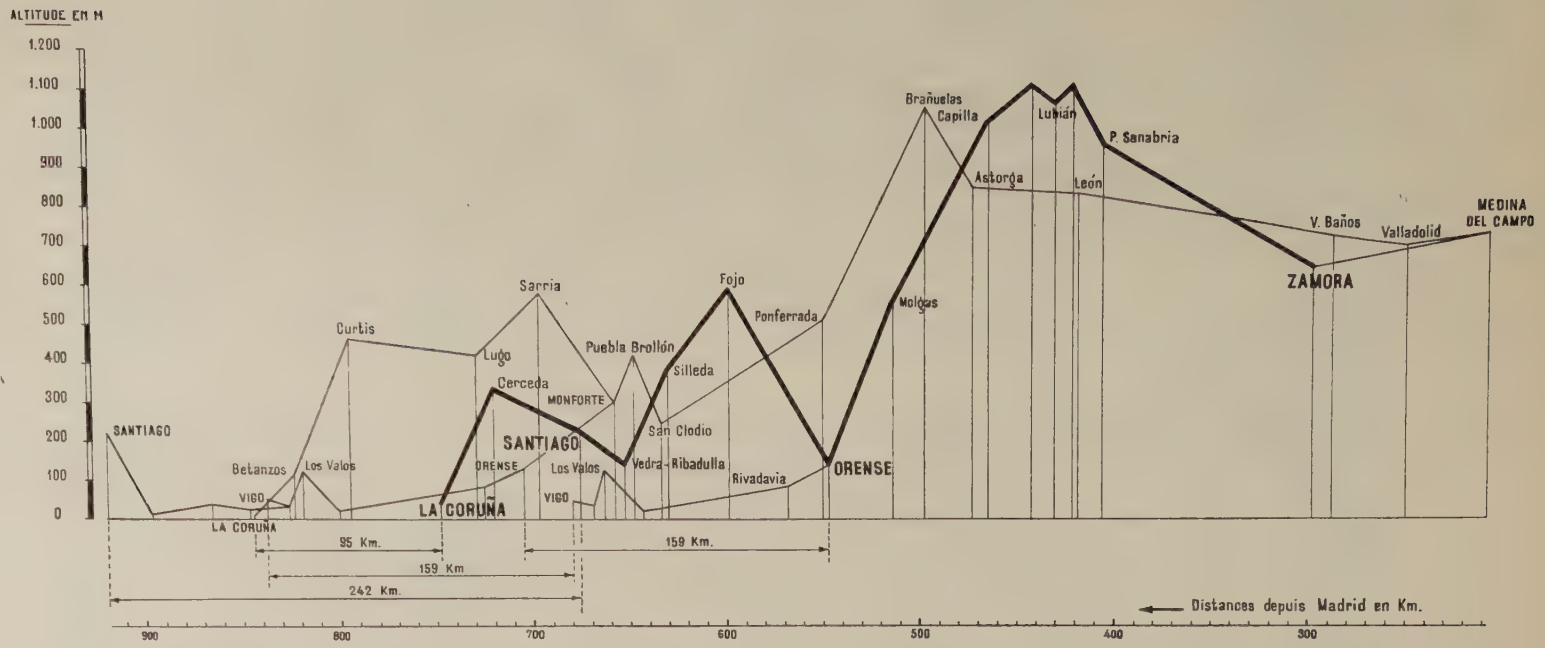


Fig. 11. — Comparison of the gradient sections and distances from Madrid via Zamora-Orense and via León-Monforte, showing the reduction in mileage via Orense, Vigo, La Coruña and Santiago.

N. B. — Distances depuis Madrid en km = distances from Madrid in km. — Altitude en m = altitude in m.

REDUCTION IN THE DISTANCE

	Via LEON km	Via ZAMORA km	Reduction km
From Madrid to Coruña	845	750	95
From Madrid to Vigo	837	678	159
From Madrid to Orense	705	546	159
From Madrid to Pontevedra	844	685	159
From Madrid to Santiago	917	675	242

The importance of the shortening of the distance between the central and other regions of Spain as far as the ports of *La Coruña* and *Vigo* are concerned, as well as the towns of *Pontevedra, Orense* and *Santiago* will result in an increase in the freight traffic with the Atlantic coast, from which all the industries of *Vigo, La Coruña* and *Le Ferrol* will benefit; in these places there are already important metalworks, shipyards, fisheries and tinned food factories. It will also encourage new industrial centres in the provinces of *Orense* and *Zamora,* which are full of latent possibilities.

Galicia, a region little frequented by tourists precisely on account of its distance, which has in addition to the beauty of its countryside, a universal stimulus for the Catholic world : *Santiago de Compostela,* a city full of spirituality, science and art, which is now only 12 h away from Madrid. The connection is assured by fast motor sets by day as well as night trains with all the comfort of sleeping cars.

Although these shortenings of the distances (fig. 11) are of great importance because of the corresponding reduction in the cost and length of the journey, we must not overlook the additional advantage of the relief given to the old *León-Monforte* line, which carries all the coal and iron traffic from the *Ponferrada* basin towards the embarkation ports of *Vigo* and *Coruña,* as it relieves the *Orense* to *Vigo* section likewise of all the traffic for *Santiago* and *La Coruña.*

All the fast passenger and freight traffic (trains carrying fish and cattle) between Galicia and the centre of Spain now travel via *Zamora-Orense,* with a great saving in cost and with absolute regularity in the timetables.

[656 .254]

The problems of warning time adaptation of automatically protected level crossings,

by Volker Bechstein, Engineer, Berlin-Treptow.

(*Deutsche Eisenbahntechnik*, No. 7, July 1958)

1. Introduction.

When, in the late 1920ies, the first automatic installations for the protection of level crossings were developed and tried out, one disadvantage which these installations had in principle was already noticeable. This disadvantage is still present, and cannot be eliminated without certain difficulties.

We are not referring to the possibility of a failure which might result in the installation failing to act and to warn road traffic. Such failures were largely eliminated or at least detected, in the course of time, through improving the connection scheme and the various components of the installation, through duplicating the contact points or duplicating the entire installation, through remote supervision from signal cabins, and through the provision of proving signals for the locomotive driver.

What we do have in mind is the contingency, often encountered in practical operation, where the level crossing is correctly protected but where the period of time from the initiation of the warning signal (red flashlight) to the arrival of the train is very long so that un-disciplined road users are tempted to cross the tracks in spite of the red flashlights, and are thus liable to cause accidents.

2. Risk of accidents due to prolonged warning time.

At a normal level crossing, the time required for the slowest and longest road vehicle to clear the crossing amounts to between 20 and 25 seconds. By adding a safety margin, the minimum warning time $t_{a\ min}$ has generally been fixed at 30 seconds. However, where several tracks are to be crossed, or where the crossing angle deviates greatly from 90°, the warning time may have to be increased to 40 or 50 seconds, and must therefore be worked out separately in each case. (For simplification's sake, a warning time of 30 seconds has been assumed throughout in the following considerations.)

In the ideal case, the train would arrive immediately after the expiry of this minimum warning period. In practice, however, this is not necessarily the case : It is common knowledge, and also apparent from earlier publications on this subject, that, at a certain distance from the level crossing, rail contacts or a long insulated track circuit are provided which, on being entered by the approaching train, cause the installation to be switched on and the red warning signal to flash. The distance of these train-actuated devices from the level crossing will obviously depend on the minimum warning period $t_{a\ min}$ on the one hand, and on the maximum train speed V_{max} on the other hand (1).

But, as the train speed may vary, and as the distance must obviously be governed by the maximum permissible speed, the ideal case will only occur with trains which approach the level crossing at maximum speed V_{max}. With a train running at half that speed, the warning period will be twice as long. Expressed in general terms, the

(1) Further details on this subject may be obtained from the author's contribution to No. 2, 1958, pp. 85 to 95, of *Deutsche Eisenbahntechnik*.

warning period is inversely proportional to the train speed.

If we consider different types of railway lines, we find that, on industrial and narrow-gauge lines, the train speeds will vary but little, as the maximum speed is low and all trains are of uniform type. On secondary lines where speeds up to 60 km/h are permitted, it is quite possible to encounter goods trains running at speeds of no more than 30 or 20 km/h so that the warning period may be doubled or trebled.

Even greater differences are encountered on main lines. A long-distance railcar may thus have a speed of 160 km/h, and this maximum speed, V_{max} will determine the distance of the train-actuated devices from the level crossing. Only in the case of this train, which may pass the crossing perhaps twice a day, is the minimum warning period of 30 seconds observed. The majority of trains on this line will pass the level crossing at speeds ranging from 60 to 90 km/h so that the warning period will generally range from 53 to 80 seconds and will thus be by 23 to 50 seconds too long. With heavy goods trains which may only be able to run at speeds of, say, 30 to 40 km/h, the warning period will amount to 120 to 160 seconds, i.e. it will be 90 to 130 seconds longer than necessary.

These data are plotted diagrammatically in figure 1. The top curve represents the warning period t_a as a function of the speed v, on the assumption of a maximum speed of $V_{max} = 160$ km/h.

$$t_a = \frac{t_{a\,min} \cdot V_{max}}{V} = \frac{30 \cdot 160}{V}.$$

The lower curve indicates the excess warning time t_1 incurred at lower speeds.

$$t_1 = t_a - t_{a\,min}$$

$$t_1 = \frac{t_{a\,min}\,(V_{max} - V)}{V} = \frac{30\,(160 - V)}{V}.$$

At the same time, this curve indicates that distance between the train-actuated device and the level crossing which would have to be chosen if, for any given speed, the minimum warning period $t_{a\,min}$ is to be adhered to :

$$s = t_{a\,min} \cdot V = \frac{30\,V}{3.6}.$$

It follows from these curves, and from the discussion so far, that, for many trains, the warning periods are considerably longer than necessary. Unnecessarily long warning times, however, reduce the safety value of the installations. The road user, who will generally be unaware of the technicalities, will assume that the red flashlight is faulty, and will cross the track in spite of it. If he uses the crossing frequently and if he has often succeeded in this negligent conduct, he becomes careless and ignores the red flashlight at all level crossings until, one day, the accident has happened.

This risk is not quite so great with level crossings which, in addition to the flashlights, are also equipped with half-barriers, since a car which has already stopped at the barrier must usually first reverse some distance before being able to by-pass the barrier. On the other hand, a driver who has observed the closing of the barrier from the distance would be able to ignore the

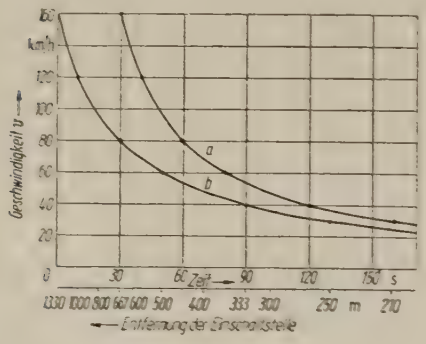


Fig. 1. — Length of warning time periods with different train speeds.

a = warning time t_a, depending on the speed;

b = excess warning time t_1 (also indicating the required distance of the actuating point from the level crossing).

N.B. — Zeit = time. — Entfernung der Einschaltstelle = distance of actuating point. — Geschwindigkeit = speed.

flashlight, the lane dividing line and the rules of the road, and by-pass the barrier without stopping.

Observations made at a half-barrier installation in the vicinity of a village, where trains rarely run at maximum speed so that the warning period is generally of the order of 1 minute, showed that whilst motor cars were correctly stopped at the barrier, pedestriams and cyclists, almost without exception, ignored the barriers and crossed the tracks. These pedestrians and cyclists were probably local residents who know the installation and have become aware of the fact that there is a long time interval between the closing of the barrier and the arrival of the train. Although such undisciplined behaviour on the part of road users may not be the rule, it is obvious that warning times of such length are conductive to carelessness.

This risk was already apparent in the early stages of development, and different methods were tried out to eliminate it. To-day, with the much greater volume and higher speed of road traffic, the risk has increased, and its elimination has become an urgent necessity. In the course of the further development of installations for the safeguarding of level crossings, which has been carried out in recent years by the « Werk fur Signal- und Sicherungstechnik », Berlin, (WSSB), this necessity has been taken into account by the addition of a further component, known as the « warning time adapter ».

According to the instructions issued by the Central Technical Office of the Deutsche Bundesbahn, and after adequate practical trials, this adapter is to be used at all level crossings where the slowest train has a speed equal to, or lower than, half the permissible maximum speed, V_{max}.

3. Possibilities of warning time adaptation.

For a discussion of the technical possibilities available for the solution of the problem of warning time adaptation, it is necessary to revert to figure 1. The lower curve indicates, on the one hand, the excess warning time t_1, incurred at speeds below maximum speed and, on the other hand, the distance s between train-actuated device and level crossing, required for maintaining the minimum warning period.

In order to achieve a uniform warning time of 30 seconds for any train speed, it is thus necessary to ascertain the speed of the train and, as a function of that speed, either to move the position of the train-actuated device in accordance with the lower curve (or, as this is technically impracticable, to select that position out of several which has the requisite distance s from the level crossings), or to adhere to a single position of the train-actuated device but impose a time lag of t_1 on the actuating time.

Both methods have been tried out in practice. In Germany, the second method has been preferred. The warning time adapters used by the Deutsche Bundesbahn in 1945, as well as the adapters newly developed by WSSB, are based on this principle. The first-named method has been adopted elsewhere, especially in the United States.

3.1. *Method based on the selection of alternative actuating points.*

An essential condition for the correct choice of the requisite actuating point is a reliable measurement of the train speed. This speed is measured by measuring the time taken by the train to cover a certain section of track formed by an insulated rail or marked by two rail contacts where the second contact generally also serves to switch on the installation. The measuring section should be short so as to eliminate, as much as possible, the influence of signals and other factors, but it must not be too short as the measurement might become inaccurate. Normally, a section corresponding to one-tenth of the warning section is chosen. In the following, for simplicity's sake, a 1 in 10 proportion for measuring section and warning section has been assumed throughout. Once that proportion has been chosen, it must be firmly adhered

to, as it serves as a basis for the whole warning time adaptation system.

Figure 2 shows the layout with the warning section s, so chosen that, with the fastest train, the minimum warning time of $t_{a\ min}$ is obtained. Before entering the warning section, the train covers the measuring section m, which has a length of 0.1 s. The drawing also shows, within the warning section, the rail contacts *K4* and *K5* which serve to switch on the installation at lower train speeds.

A train passing the section at the maximum speed of 160 km/h requires $t_{a\ min} = 30$ seconds to cover the warning section and the tenth part of that time, i.e. $t_o = 3$ seconds, to cover the measuring section (cf. fig. 3). For this train, contact *K2*, which has a distance of 1 330 m from the level crossing, must be operative in switching on the warning installation. Another train may run at a speed of, say, 80 km/h and will therefore, as can be seen from figure 1, require $t_a = 60$ seconds to cover the warning section and $t_m = 6$ seconds to cover the measuring section. If a time relay *V6* with a time lag of 6 seconds is provided, as shown in principle in figure 4, this relay will drop during the passage of the measuring section and will prevent, by its contacts, the operation of the warning signals by rail contact *K2*; on the other hand, that rail contact will now be made operative, which ensures the minimum warning time for a speed of 80 km/h, viz. contact *K4* in figures 2 to 4 which has a distance of 667 m from the level crossing. In the case of a train running at 40 km/h, the time required to cover the warning section increases to $t_a = 120$ seconds and the time to cover the measuring section to $t_m = 12$ seconds. In that case, another time relay *V12*, with a time lag of 12 seconds, will drop, and the corresponding rail contact *K5* will be made operative, whilst the intermediate contacts *K2* and *K4* are cut out.

If the measured time t_m is less than 12 seconds, the time relay *V12* is no longer able to drop and to make contact *K5* operative. A subsequent dropping of the relay is prevented by the operation of rail contact *K2*. In that case, the previous contact (i.e. *K4* in our example) remains operative.

In theory, if it is desired to adhere to the minimum warning time for any train speed, it would be necessary to provide a time

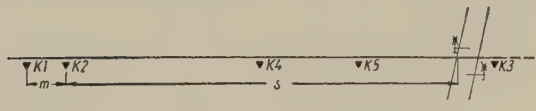


Fig. 2. — Layout of an installation for the protection of a level crossing, with measuring section m and additional rail contacts *K4* and *K5*.

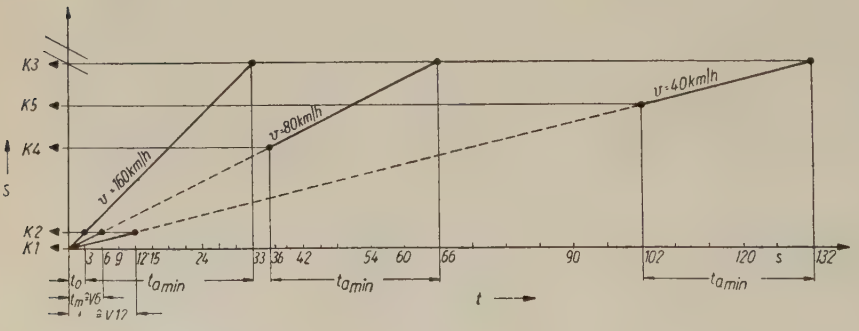


Fig. 3. — Illustrating the method based on the selection of alternative actuating points.

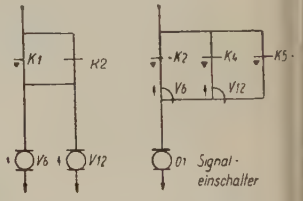


Fig. 4. — Connection diagram, in principle, for the method based on the selection of alternative actuating points.

N.B. — Signaleinschalter = signal switch.

relay for any measured time t_m, which would make a corresponding rail contact operative and all intermediate contacts inoperative. In the case of a slow train, the time relays would then drop one after the other, and would make the rail contacts operative one by one until the contact corresponding to the measured train speed becomes operative. In lieu of the multiplicity of time relays, it is also possible to use a mechanical device, cam disks, step switches or the like.

In practice, economic reasons militate against the use of so many rail contacts. If insulated rails are used, their number is also restricted by the fact that a certain minimum length per rail is required. It is therefore necessary to forgo a linear adaptation of the warning time which would result in a constant warning period of $t_{a\ min}$ at all train speeds, and to resort to a system of stepwise adaptation where the number of time relays and corresponding rail contacts is confined to one or two, as assumed in the above example.

This means that a warning time of 30 seconds applies at certain speeds only, e.g. in our example, at 160, 80 and 40 km/h. Let us assume that a train runs at a speed of 81 km/h. In that case, the time measured over the measuring distance amounts to approx. 5.9 seconds so that the first time relay is no longer able to drop, and rail contact *K2* remains operative. The same applies to a train running at a speed of 41 km/h except that the signals are operated by contact *K4* because the time relay *V6* has been able to drop in the meantime. In both cases, the warning period becomes 59 seconds. It is thus possible for the warning period to vary from 30 to 59 seconds, but the latter cannot be exceeded.

If most trains in the example here considered run at speeds of approx. 90 and 50 km/h, respectively, it is undesirable to use 80 and 40 km/h as critical speeds as this would result in a high incidence of the long warning period. In that case, it would be desirable to choose, say 95 and 55 km/h as critical speeds so that most trains would have a short warning period.

Although, with this system, the warning time is not always reduced to the minimum, the advantage is still considerable compared with a system without warning time adaptation.

Proposals have been made for a simplified version of this system where two rail contacts are used, one for maximum speed, operative in the normal position, and one for medium speed. If a slow train is to use the line, the other rail contact is made operative by means of an intervention from the nearest signal cabin. Admittedly, the objective can also be attained in this way, but the operation is not automatic and adds to the duties of the signalman. Moreover, the system is not foolproof as there is no automatic interlocking.

3.2. *Method based on the variation of the time lag imposed.*

The principle of the time lag system has already been discussed in section 3. In this case, too, the exact measurement of the train speed is an essential prerequisite. The measuring section is usually arranged in the same way as described above, and again, the speed is measured by measuring the running time. The task of the apparatus is now to delay the operation of the road signals by the time t_1 (fig. 1) as a function of the train speed.

The length of the measuring section is one-tenth of the length of the warning section. A train passing at maximum speed requires $t_o = 3$ seconds to cover the measuring section and $t_{a\ min} = 30$ seconds to cover the warning section; the time t_1 is zero. A train running at a speed equal to half the maximum speed requires $t_m = 6$ seconds to cover the measuring section, and $t_a = 60$ seconds to cover the warning section.

In this case, t_1 amounts to 30 seconds, and it is by this time that the operation of the road signals must be delayed.

On the assumption of constant speed, the lengths of the sections are proportionate to the running times required to cover them :

$$\frac{s}{m} = \frac{t_{a\,\min}}{t_o}.$$

With $t_a = s/v$ and $t_m = m/v$, one obtains :

$$\frac{s}{m} = \frac{t_a\, v}{t_m\, v},$$

so that the speed v can be eliminated. On the other hand, the time t_a consists of the components t_1 and $t_{a\,\min}$:

$$t_a = t_1 + t_{a\,\min}.$$

section which is in excess of the running time taken by the fastest trains, just as t_1 represents a similar excess time for the warning section. t_2 can easily be ascertained by measurement. As the requisite delay t_1 always amounts to ten times t_2, it is not difficult to obtain the required delay as a function of the measured time. What is needed for this purpose is a storage device by which values are stored during the period t_2, and released during the period t_1 corresponding to ten times the storage

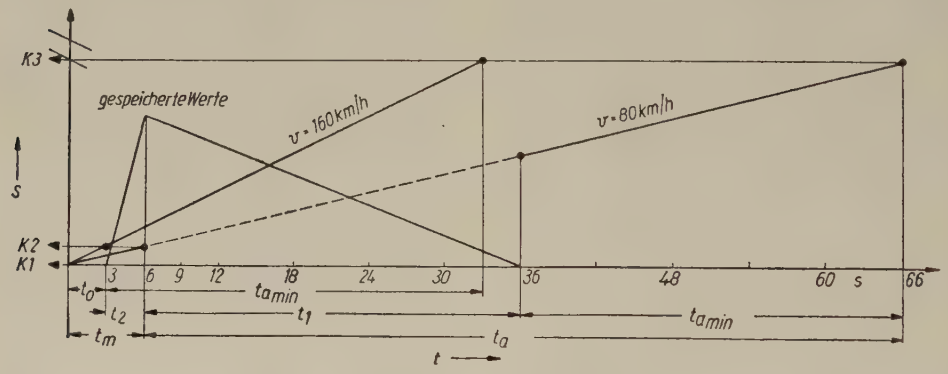


Fig. 5. — Illustrating the method based on the imposition of a time lag, with one storage reservoir.

N.B. — Gespeicherte Werte = stored values.

Similarly, the time t_m can be de-composed into two components at the same ratio as t_1 and $t_{a\,\min}$:

$$t_m = t_2 + t_o$$

After transformation, one obtains :

$$t_1 = t_a - t_{a\,\min}$$

and, correspondingly :

$$t_2 = t_m - t_o\,.$$

As the length ratio of the two sections is $s/m = 10$, it is possible to substitute $t_m = 0.1\ t_a$, and $t_o = 0.1\ t_{a\,\min}$, so that one obtains :

$$t_2 = 0.1\ (t_a - t_{a\,\min}), \text{ or } t_2 = 0.1\ t_1\,.$$

The time t_2 represents that part of the running time of a train over the measuring period. When the storage device has returned to the zero position, the time $t_1 = 10\ t_2$ has elapsed, and it is time for the signals to be switched on. It is also possible for a second storage device to store values over a period ten times as long, while the first storage device is cut out. When both stores have accumulated the same number of values, it is time for the signals to be switched on because the time t_1 has elapsed. In figures 5 and 6, these two possibilities are shown diagrammatically.

The storage device may assume different forms, the main point being that the multiplication of the measuring time by ten is carried out with sufficient accuracy. Similarly, it is necessary for the initial time allowance t_o to be adhered to accurately, since any error in t_o will affect the minimum warning time $t_{a\,\min}$ by ten times as much.

3. 21. *Mechanical storage device.*

The first experiments were carried out with mechanical devices. A motor is used to move, during the period t_2, a cam disk away from the zero position by a certain amount. When the movement begins, a contact is opened. During the period t_1, the motor returns the disk to the zero position by means of a 1 in 10 gear drive. When the disk has returned to the zero position, the contact is closed, and the road signals are operated. This device can be

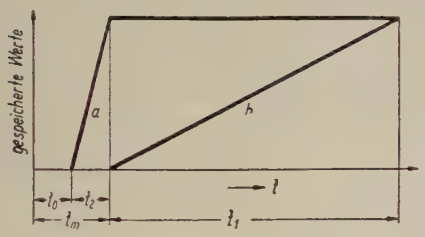


Fig. 6. — Method with two storage reservoirs.
a = first reservoir;
b = second reservoir.
N.B. — Gespeicherte Werte = stored values.

varied in a number of ways. For instance, one may arrange for a contact arm to move, during the period t_2, around a cam disk which begins to run at one-tenth of the speed in the same direction at the commencement of period t_1. After the time t_1 has elapsed, the cam again reaches the contact so that the latter becomes operative. It has also been suggested that a motor should be used to modify, during the period t_2, a rheostat series-connected with a second motor which is provided with a cam disk and, because of the resistance, runs correspondingly slower.

In the following, a more detailed description is given of the storage system which was used by the Deutsche Reichsbahn before 1945 in conjunction with automatic warning installations [1]. This system is illustrated by figure 7. When rail contact *K1* (fig. 2) is operated, motor *a* begins to run. The motor moves, at a speed V_1, an arm *b* carrying a set of contact springs which slide on a stationary cam disk *c*. When the time t_0 has elapsed, the contact springs run up against the cam and are closed. If rail contact *K2* is operated after the time t_2 has elapsed, the coil of the magnetic coupling *d* is energized. In consequence, both the coupling (via gear wheels e_1 and e_2) and the cam disk (via gear wheels e_3 and e_4) are moved in the same direction as the contact arm. The gear ratios of the two pairs of wheels are so chosen that the cam disk moves at a speed V_2 which is 10 % higher than that of the arm :

$$V_2 = 1.1\ V_1\ .$$

The contact therefore appears to run back on the cam disk at a speed of V_3, where :

$$V_3 = V_1 - 1.1.\ V_1 = -0.1\ V_1\ .$$

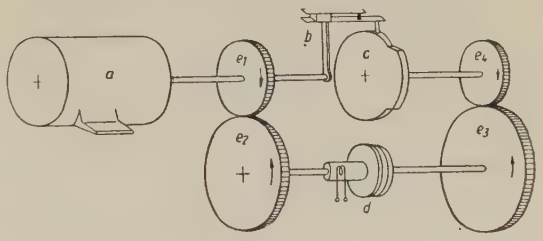


Fig. 7. — Illustrating the principle of a warning time adapter with mechanical storage reservoir.
a = motor;
b = lever;
c — cam disk;
d = magnetic coupling;
e_1 to e_4 = gear wheels.

The stipulation that the stored values must be released in a time corresponding to ten times the storage time has thus been fulfilled. After t_1 has elapsed, the set of contact springs again drops off from the cam, and the contact is opened. In this way, the hitherto stored instruction for the installation to be switched on is now released. If a train passes the section at a maximum speed, *K2* is reached before the arm runs up against the cam so that the contact is not closed and the installation can be switched on at once.

The apparatus also comprises a centrifugal governor and several cam disks and contacts at the coupling, not shown in the drawing, which are required for verification purposes and for the restoration of the zero position.

In contrast to the devices described in section 3.1, the devices based on this or similar principles permit a linear adaptation of the warning period to the speed, i.e. the minimum warning time is achieved at all speeds.

3. 22. *Electro-mechanical storage devices.*

Some electro-mechanical systems have also become known. For instance, it is possible, to arrange two rotary selectors in such a way that one of them, *W1*, runs during the period t_2 at the impulse frequency f_1. During the time t_1, a second rotary selector *W2* runs at an impulse frequency f_2 ten times lower than f_1 while the first selector is cut out. When both selectors are in the same position, the signals can be switched on. With this arrangement, a special time relay V_o must be provided for the initial time allowance t_o (fig. 8), and the adaptation is again stepwise (fig. 9). It is however possible to choose, without great expense, a great number of small steps so that there is practically no difference compared with linear adaptation. For instance, if a step of 5 seconds is chosen, the first selector must move by one step every half-second. Since the maximum storage capacity must be about 15 seconds, the selectors require about 30 positions. This can be achieved with normal rotary selectors.

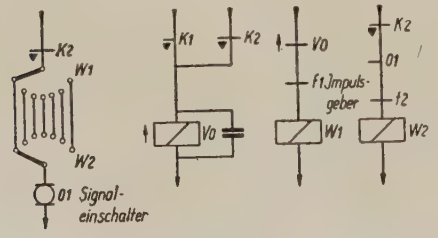


Fig. 8. — Connection diagram, in principle, of a warning time adapter with electro-mechanical storage reservoir.

N.B. — Signaleinschalter = signal switch. — Impulsgeber = impulse transmitter.

It is also possible to resort to relay storage instead, which can be built up and reduced. Figure 10 shows the principle of a relay storage where impulses are stored and released in binary sequence : the corresponding impulse transmitter is also indicated. The latter consists in a relay interrupter with capacitive retardation, consisting of relays *G* and *Ga*. If condensers are used for the control of the impulse frequency, it

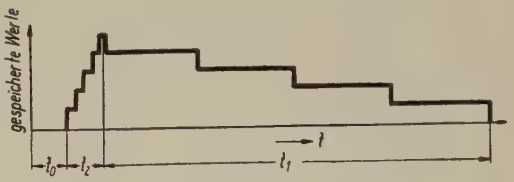


Fig. 9. — Curve of stored values for the systems illustrated in figures 8 and 10.

N.B. — Gespeicherte Werte = stored values.

is advisable to use only one, with a discharge time adapted by parallel-connected resistances to the required impulse frequency. As a result, the frequency ratio will remain constant, irrespective of any change in capacitance in the course of time. This is of particular importance in view of the well-known inconstancy of electrolyte condensers. Relays *Gb* and *Gc* are required for the inversion of the retardation. Relays *S*, *Sa*, *Sb* and *Sc* are storage relays, whilst *A*, *Aa*, *Ab* and *Ac* are auxiliary storing relays and *E*, *Ea*, *Eb* and *Ec* auxiliary de-storing relays.

When a train passes rail contact *K1*, the relay interrupter can start to run. The first delay, with parallel-connected resistance *R1*, corresponds to the time t_o. With the first impulse, resistance *R1* is disconnected through the auxiliary relay *Gb* so that the impulse frequency is now f_1, governed by the parallel resistance *R2*, now operative. In addition, the first impulse serves to

energize the auxiliary storing relay *A*. This, in conjunction with *A1*, energizes the storage relay *S* which forms, via *S1*, a self-locking circuit. Through contact *S2*, relay *Aa* is made operative. At the next impulse, this relay as well as, through contact *Aa1*, relay *Sa* are energized. *Sa* forms a self-locking circuit, whilst that of *S* is interrupted by means of contact *Aa2* so that *S* drops. The alternators *S2* and *Sa2* reverse so that the next impulse will again energize *A*, and the next-but-one *Ab*. The further impulses are similarly stored in binary sequence. The storage relays *S* work in the manner illustrated by figure 11.

When the train passes *K2*, the latter contact causes the auxiliary de-storing relays, instead of the auxiliary storing relays, to be connected to impulse contact *G3*. In addition, resistance *R2* is disconnected together with relay *Gc* so that the impulse transmitter now works with the ten times lower frequency *f2*. For instance, if eight impulses were stored during the time t_1 so that *Sc* alone was energized, the next impulse will cause the auxiliary de-storing relay *Ec* to be energized. Contact *Ec1* disconnects the storage relay *Sc*, *Ec2*, *3* and *4* serve to energize the storage relays *S*, *Sa* and *Sb*. In consequence, the relay storage is reduced in binary sequence in analogy to the way in which it has been built up, i.e. from bottom to top in figure 11. When as many impulses have been taken out as had been stored, all the storage relays have returned to the zero position so that the signal-operating relay *O1* can again be energized. Figure 9 applies again.

With the connection shown, it is possible to store 15 impulses. Since, in view of the possible difference in speed, provision must be made for storing about 15 seconds, one step, i.e. the maximum increase in the warning time, would amount to 10 seconds. This period can be reduced to half that time if 31 impulses can be stored. This can be done by the appropriate addition of one auxiliary storing relay, one auxiliary de-storing relay, and one storage relay. Generally speaking, the number of impulses that can be stored is $2n - 1$, where n is the number of storage relays.

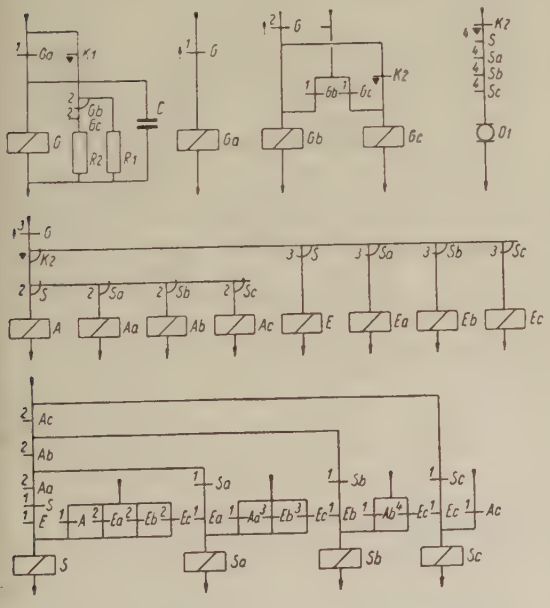


Fig. 10. — Connection diagram, in principle, of a warning time adapter with relay storage.

A, Aa, Ab, Ac = auxiliary storing relays;
E, Ea, Eb, Ec = auxiliary de-storing relays;
G, Ga = relays of relay interrupter;
Gb, Gc = relay for reversal of retardation;
S, Sa, Sb, Sc = storage relays.

3. 23. *Electric storage.*

All the systems described so far suffer from the disadvatage that they contain mechanically operated parts which require servicing and are subject to wear. Also, in some cases, the power requirement is comparatively high. This can be avoided if a purely electric storage system is used.

It is easy to visualize the stored value shown in figure 5 as potentials. The potential would have to increase at a linear rate during period t_2, and would have to decrease again during period t_1, ten times as long. Alternatively, the potential might first drop and then increase. In any case, the flashlight installation must be switched on when the point of origin has again been reached.

Charges, and thus also potentials, can be stored by means of capacitances, but the charging and discharging processes do not proceed at a linear rate. Since linearity is an essential condition for reliable working, it is only possible to use very short, practically linear sections of the total charging or discharging curve. As a consequence, and because of the very long periods of time required, extremely large condensers and highly sensitive relays would be needed.

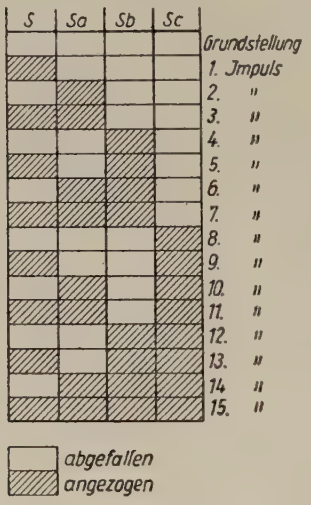


Fig. 11. — Sequence of storage relay operation for the connection scheme shown in figure 10.

N.B. — Grundstellung = zero position. — Abgefallen = dropped. — Angezogen = energized.

A simpler and more accurate method of obtaining a linear change of potential is by using electronic sweep apparatus of the type used in many varieties for horizontal deflection in cathode ray oscillographs and television sets. The working of most of these devices is based on the fact that, in pentodes with constant grid potential, the anode current is constant even if the anode voltage is variable. Therefore, if a condenser is charged or discharged by means of a pentode instead of a resistance, the potential will vary at a linear rate (fig. 12).

The change in the potential at the outlets of the sweep apparatus has certain similarities with the required change. Generally, the sweep voltage is a periodic potential, generated by the natural oscillation frequency. It is, however, possible without major modification to arrange the connection in such a way that a sweep period is covered merely as a result of an external impulse (rail contact impulse). The potential drops at a linear rate whilst the voltage increase should, for most applications, be as short as possible so that an exponential curve can be accepted without detriment. For the purpose of warning time adaptation, however, even the voltage increase must follow a linear rate. The increase might be controlled by a second pentode. Alternatively, it is possible to use two sets of sweep apparatus, as with the system consisting of two step switches. In this case, the two voltages must be compared with each other.

There is, however, also a type of sweep circuit with which it is possible, by simple means, to generate linear voltage increases and voltage drops. If a square voltage is connected to the inlet of the circuit known as Miller Integrator [4], one obtains an output voltage U_a proportionate to the time integral of the input voltage, i.e. a delta voltage (fig. 13). The input voltage U_e is connected via the resistance R to the grid of a high-boost amplifier with an input

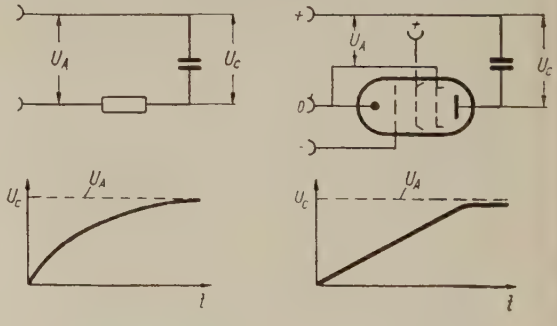


Fig. 12. — Increase of potential during the charging of a condenser.
Left : by means of a resistance;
Right : by means of a pentode.

resistance as high as possible. Through condenser C, the output voltage U_a is fed back to the control grid of the amplifier. As the input resistance of the amplifier should be very high, the current flowing through condenser C is nearly equal to the current flowing through resistance R. Hence the equation :

$$\frac{U_e - U_g}{R} = C \cdot \frac{\mathrm{d}\,(U_g - U_a)}{\mathrm{d}t}.$$

Because of the high amplification factor, the grid voltage U_g can be assumed to be small by comparison to U_e and U_a, and can therefore be neglected so that the following approximation is valid :

$$\frac{U_e}{R} = -C \cdot \frac{\mathrm{d}\,U_a}{\mathrm{d}t}.$$

One thus obtains for the output voltage U_a :

$$\frac{\mathrm{d}\,U_a}{\mathrm{d}t} = -\frac{U_e}{RC}$$

$$U_a = -\frac{1}{RC}\int_0^t U_e\,\mathrm{d}t + U_a.$$

where U_A is the anode potential at the time $t = 0$. Moreover :

$$U_a = U_A - \frac{U_e}{RC} \cdot t.$$

It follows from this equation that U_a will rise at a linear rate with a constant positive input voltage U_e, and will drop at a linear rate with negative input voltage U_e.

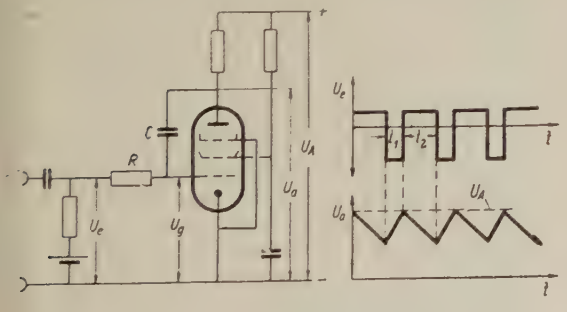


Fig. 13. — *Left :* Connection diagram, in principle, of the Miller Integrator. — *Right :* Input and output voltage as a function of time.

Strictly speaking, the voltage rise or drop is not quite linear as the grid voltage U_g has been neglected. The finite value of U_g will cause a deviation from linearity which is, however, of no practical importance because of the high values of R and U_e.

The RC term at the beginning and the initial grid voltage are required when a continuous integration of a rectangular curve is desired, as the mean value must be constant in relation to the initial grid voltage.

For the storage purposes in connection with the warning time adapter, all that is required is a single, very slow sweep action with a constant ratio, such as 1 in 10, between the period of voltage drop and that of voltage rise. The last equation applies to the voltage drop. If the voltage rise is desired to take place in ten times that period of time, it is necessary either for the voltage U_e to drop to one-tenth of its value, or for R or C to rise to ten times their value. Moreover, the input voltage U_e must change its sign. As we have to do with a single process and constant values, the RC term at the beginning and the initial grid potential can be left out. If, in addition, a sensitive relay is connected to the anode circuit, the storage device meets the specified requirements.

The voltage changes as follows. In the zero position, a negative voltage U_e is connected so that U_a is equal to U_A; there is no anode current, and the relay has dropped. After the initial time allowance t_o has elapsed, a positive voltage is connected : the output voltage begins to drop at a linear rate; an anode current is flowing so that the relay is energized immediately after the switch-over. After a period t_1, U_e again assumes a negative value. Its absolute value must drop to one-tenth; alternatively, its value remains constant but either R or C increase to ten times their value. The voltage increases again, but the increase takes place in ten times the period of time. Immediately before U_a again

reaches the anode potential U_A, the relay drops and operates the warning signals.

The simplest way of obtaining the reversal is by reversing the input voltage. If the 24 volt tension available in the installation is chosen as the negative voltage, the positive voltage must amount to 240 volt which is available as anode potential U_A. In this case, R and C remain constant (fig. 14). The determination of these values is very simple : it can also, again, be based on the equation :

$$U_a = U_A - \frac{U_e}{RC} \cdot t .$$

Hence :

$$RC = \frac{U_e\, t}{U_A - U_a} .$$

For U_A and U_e, 240 volt are chosen; t is the required storage capacity t_1 which must be approx. 15 seconds; U_a is the lowest value of the output voltage which may amount to about 40 volt.

Hence :

$$RC = \frac{240 \cdot 15}{240 - 40} = 18\,\text{s}.$$

This result must be spread over R and C. It has already been mentioned that a high value of R has a favourable influence on linearity. If one therefore chooses $R = 3\text{M}\Omega$ it follows that C must be $= 6\mu\text{F}$. Such a small condenser (which, in the form of an MP condenser for 350 volt, measures $45 \times 50 \times 30$ mm) is not attained by any other sweep apparatus. With the apparatus previously described, about ten times that capacitance would be required, and for the voltage rise even about a hundred times that capacitance.

4. The new warning time adapter, developed by WSSB.

The decision as to which system should be used for the new warning time adapter was not difficult. It was decided to adopt the system last described, since the use of electronics is a trend common to all spheres of technology, and since the other systems have certain drawbacks, already discussed. Structurally and electrically, the new apparatus had to be adapted to the installations for the protection of level crossings, newly developed by the VEB Werk für Signal- und Sicherungstechnik, Berlin. The general arrangement and design of those installations have already been described in detail in earlier publications [2] [3]. In the following, these installations are therefore assumed to be known.

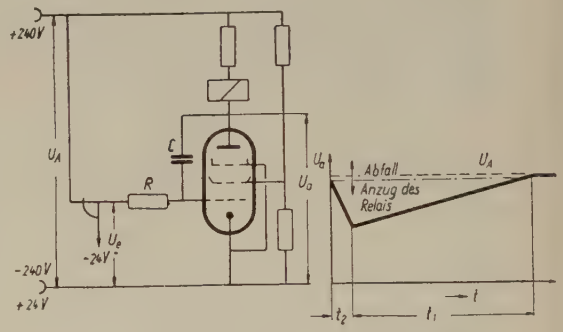


Fig. 14. — *Left :* Application of Miller Integrator to warning time adaptation. — *Right :* Change of potential during the passage of a train.

N.B. — Abfall des Relays = relay dropped. — Anzug des Relais = relay energized.

4. 1. *Circuit arrangement.*

By and large, the circuit arrangement of the new warning time adapter corresponds to the one already described with the aid of figure 14. To this are added the relays required for the adaptation to the basic connection scheme. There is, however, one important difference : With the arrangement shown in figure 14, a special delay was assumed for the generation of the initial time allowance t_o. With the arrangement actually adopted, the initial time allowance t_o forms part of the voltage drop. This is achieved by connecting a resistance parallel to relay 18 in the anode circuit. Owing to this division of the current, the relay is not energized immediately, but if the resistance is correctly rated, only after the time t_o. The positive voltage must there-

fore be connected to the valve grid as soon as the measuring contact is actuated. Relay 18 must drop at the same output voltage at which it had been energized previously as it is otherwise not possible to ensure that the measured time is multiplied by ten. This condition is realized by means of a second winding which, during the rise of the anode potential, excites the relay in

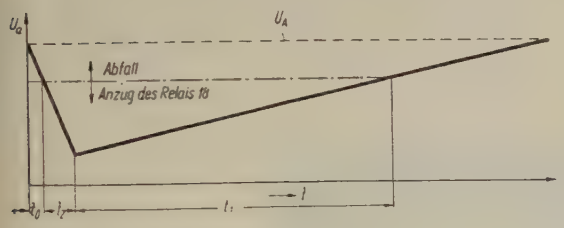


Fig. 15. — Change of potential during the passage of a train, with the new WSSB type warning time adapter.

N. B. — Abfall des Relais 18 = relay 18 dropped. — Anzug des Relais 18 = relay 18 energized.

the opposite sense to an extent corresponding to the difference between energizing and release excitation. The further increase in the output voltage up to the anode potential U_A takes place during the next 30 seconds but is of no significance to the connection scheme. The voltage-time diagram thus assumes the form shown in figure 15.

The resistance parallel to relay 18 takes the form of a variable rheostat so that the time allowance t_0 which, in certain circumstances, may also assume higher values than 3 seconds, can be accurately pre-set. Similarly, to permit the adjustment of tolerances, the positive input voltage is tapped by means of a potentiometer from the anode potential which is therefore slightly above 240 V. Filament and anode voltage are taken from the grid by means of a transformer. The anode voltage is rectified by means of a selenium rectifier. The primary side of the transformer also contains a second winding which, in the case of a grid supply failure, is fed from the 24 V battery by means of a chopper.

Rail contact relay 20 is connected to the basic circuit scheme by the same circuit as relays 01 and 02. Relay 54 corresponds to the auxiliary signal relay in the circuit scheme used for home signals or block signals. Here, it also takes the place of the contacts (essential for the connection) of relays 01 and 02 at the stop lights and at the time relay 05 so that the signals can only operate when relay 54 is energized. This can only happen when rail contact *K2* has been operated and relay 18 is in the zero position.

Figure 16 shows the complete connection diagram of the warning time adapter, which supplements the basic connection scheme(2). Rail contact *K7* is passed by a train. (The contact numbers *K1* to *K6* are already used in the basic connection scheme so that the new rail contact is called *K7*, and the one for the opposite direction *K8*. *K7* corresponds to contact *K1* in figure 2. Con-

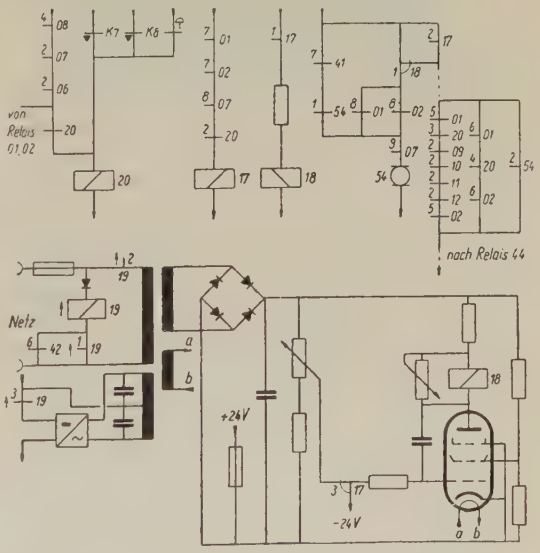


Fig. 16. — Connection diagram of new WSSB type warning time adapter.

N.B. — Von Relais... = from relay... — Nach Relais... = to relay... — Netz = grid supply.

(2) Cf. *Deutsche Eisenbahntechnik*, vol. 6 (1958), n° 2, p. 85, fig. 5.

tact *K2* in figure 2 corresponds to contacts *K1* and *K2* in the basic scheme, just as *K3* corresponds to *K3* and *K4* in the basic scheme, all in duplicate). When contact *K7* is passed, relay 20 is energized and forms a self-locking circuit. Through contact 20,2 relay 17 is energized and connects, by means of contact 17,3, a voltage of + 240 V instead of — 24 V to the grid of the valve. In consequence, the output voltage begins to drop at a linear rate. By means of contact 20,3 and 20,4 as well as 17,2, the working of rail contact *K7* and *K8* as well as that of relay 18 is verified.

direction are operated, contacts 07,8 and 07,9 interrupt the circuits of relays 17 and 54. As had already been done in the basic connection scheme, a key is provided in parallel to the rail contacts. In testing the installation, the signal lineman is therefore able to imitate the run of a train from the switchrack by operating the proving keys in their correct sequence.

On multi-track lines, the apparatus is provided for each track, complete with all relays. It is usually possible to do without measuring contacts for wrong-way movements.

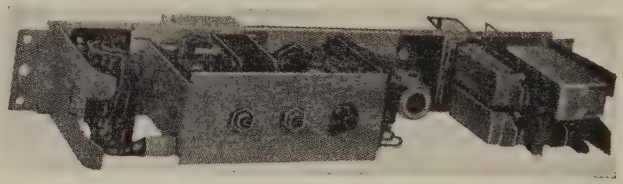


Fig. 17. — Structural design of WSSB type warning time adapter.

When the initial time allowance t_o has elapsed, the output voltage has dropped so far that relay 18 can be energized. Before that, the opposing winding had been disconnected by contact 17,1. Contact 18,1, which is now open, prevents the operation of relay 54 after the time t_2 has elapsed if rail contact *K1* and *K2* are operated. These rail contacts enable the relays 01 and 02 to be energized which take part in the same self-locking circuit as relay 20. Their contacts 01,7 and 02,7 disconnect relay 17 which re-connects the negative voltage (— 24 V) to the grid of the valve so that the output voltage rises again, but in ten times the period of time. Contact 17,1 connects the opposing winding of relay 18 so that the latter drops after the time t_1 at the same voltage at which it has been energized before. As soon as contact 18,1 has returned to the zero position, relay 54 is energized and is now able to switch in the signals. Thirty seconds later, the train reaches the level crossing.

To prevent the apparatus from working when the rail contacts in the opposite

It is, however, also possible to use but one warning time adapter where duplication is confined to the rail contact relay 17 and relay 54. If a second train on a second track enters the measuring section as long as the device for the first track is measuring or retarding, it is necessary to bridge contact 18,1 by means of the two rail contact relays 17 parallel to 18,1, since the second train may be faster than the first so that the operation of the warning signals must not be retarded. This arrangement has the disadvantage that, whenever a second train comes along while the process of measuring and retarding has already begun for the first train, the installation must be switched on at once. The warning time is prolonged, especially if the second train is slower. The advantage is that, apart from the two additional relays, only one set of apparatus is required.

As the statistical calculations carried out by the Central Technical Office (TZA) of the Deutsche Reichsbahn showed that the probability of such a meeting of two trains at the level crossing is not as low as had

first been assumed, it was decided by that office that each track should be equipped with a complete set.

4. 2. *Structural design.*

In the structural design of the apparatus, the attempt was made to assimilate the apparatus as much as possible to the components of the existing WSSB type relay rack. The 18-part bar for structural units, known from telecommunication technique, is provided in duplicate for single-track installations, and in triplicate for double-track installations, for the accommodation of the flat-type relays. This unit rack is also well suited to accommodate the components of the warning time adapter. A relay rack and a tag rack can be mounted in the normal positions without modification. To carry the power supply unit, the condensers and resistances as well as the valve, a special base plate is screwed on. Potentiometer and push button are mounted on a second plate, further in front, so that they are more easily accessible. The whole assembly is covered with the usual plastic cover. Relay 54 must be a signal relay, and is therefore mounted at a free position in the signal relay group.

The chopper requires vertical mounting, and can therefore not be accommodated in the unit rack. Its socket is mounted in the immediate vicinity of the bar on an angle iron at the back of the rack. Figure 17 shows the warning time adapter alone, and figure 18 an entire relay rack for a double-track installation equipped with only one warning time adapter for both tracks.

For double-track lines, it is necessary to use two unit bars. The second bar corresponds to the first except that the power supply unit with chopper and relay 19 is omitted, as the second bar is supplied from the power supply unit of the first bar.

The preparation of the layout plan is beset with one difficulty, viz. the choice of the correct position of the lineside proving signal. With installations based on the basic connection scheme, the proving signal is located at the position which the fastest train reaches 10 seconds after passing the operating contacts *K1* or *K2*. At that moment, the proving signal must show white flashlight. In the case of an installation provided with warning time adapter, this condition only applies to trains running at maximum speed. With slower trains, the operation of the signals is delayed so that the proving signal is not yet flashing by the time the train passes the signal.

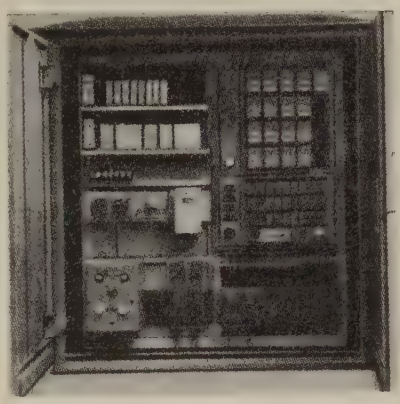


Fig. 18. — Relay box for WSSB type double-track half-barrier installation with warning time adapter.

In order to provide an indication to the engine driver that, in this case, the signal may appear later, the Central Technical Office of the Deutsche Reichsbahn has decided to provide a second proving signal half-way between the first proving signal and the level crossing. A train running at half the maximum speed will reach that signal at the moment at which the signal begins to flash. This arrangement is not quite unequivocal as it cannot be clearly ascertained whether the signals have failed or are merely delayed. With the basic connection scheme at present in use, however, it is hardly possible to adopt a different solution. The general trend is towards elimination of proving signals, at any rate on main lines. In that case, the problem just referred to would cease to exist. But before a final decision can be made, it is

necessary to gather experience in this matter. It would also be necessary to adopt a basic connection scheme based on different principles.

5. Potential sources of faults and errors.

The connection schemes for installations for the protection of level crossings are so designed that all possible faults are indicated. Owing to the duplication of the train-actuated devices, a complete failure of the installation is highly improbable. If it happens the proving signal still serves as a safety device. Belated actuation is practically impossible. The new warning time adapter constitutes a new potential source of errors. Any conceivable sources of trouble must be taken into consideration. On no account must any error be allowed to be on the un-safe side. It is always possible to concede, exeptionally, a prolongation of the warning period up to the maximum period not modified by the train speed; but a shortening of the warning period must be ruled out.

5. 1. *Faults caused by the apparatus.*

Before discussing the new WSSB type warning time adapter, brief reference may be made to the potential faults of other systems. With the method based on the selection of alternative actuating points, the accuracy of timing depends on the time relays *V6* and *V12*. If these relays drop prematurely, rail contacts *K4* and *K5* will be made operative also for fast trains so that the warning period is shortened. It is therefore necessary to reckon with the shortest possible retardation as governed by voltage fluctuations, tolerances of resistances and condensers, etc. In practice, the time lags, and thus the warning times, will therefore always be slightly longer than desired.

With all time lag systems, two factors are important, viz. the initial time allowance t_o, and the multiplication of the measured time t_2 by ten. If t_o is too short, the above remark applies, and a slower train speed is simulated. The error is multiplied by ten in its effect on the warning period.

If the multiplication of the measured time is not done accurately, the warning periods will be shortened if t_1 becomes greater than 10 t_2. With the mechanical systems, the multiplication of the measured time (and, with the system here described in greater detail, also the initial time) depends on the constancy of the rotary speed which may be affected by voltage fluctuations and by mechanical resistances. Centrifugal contacts ensure that the warning time adapter can only work when the nominal r.p.m. is available; otherwise, the installation is cut out without delay.

If, in the case of electro-mechanical systems, only one retarding condenser is used as already described, where the different time lags are obtained by means of parallel-connected resistances, one source of error is already eliminated. The muliplication must always be constant, irrespective of the changes of the condenser. Voltage fluctuations will only have an effect if the voltage during the retardation process differs from the voltage during the measuring process. The initial time allowance must be so adjusted that, if all unfavourable factors are taken into account, this period cannot be less than 3 seconds.

Conditions are similar with the new WSSB type warning time adapter. The multiplication of the measured time is dependent on both voltages. If these change uniformly, no error will occur; this is the case if the grid voltage rises. In that case, the battery voltage will rise at the same rate, as the battery is buffered from the same grid and no load is caused by the installation during the retardation time. Admittedly, the initial time allowance will be slightly shortened, and this possibility must be taken into account in the pre-setting. If the grid voltage drops below its normal value, the battery voltage will only partly follow suit. The ratio is modified, but not to the un-safe side; the warning period becomes slightly longer. The initial time allowance, too, becomes longer so that the warning period is further increased by another few seconds. But this increase does not diminish the value of the warning time adapter; the additional times are small; they can, even under unfavourable condi-

tions, not amount to more than 10 seconds. Moreover, the transformer can be connected on the primary side to a smaller number of turns whenever the grid voltage is too low.

During a grid failure, the two voltages cannot change differently since both originate from the same source. To avoid the possibility of short-time supply failures or loose contacts in the feeder causing faults in the time measurement, the supply pilot relay cuts out automatically and cannot be energized before the crossing barrier opening relay (relay 42) has operated.

If a train should run at such a low speed that the anode potential reaches its minimum value during the measured time t_2, it is not possible to measure the remainder of the time. The delay is therefore too short by a period of time corresponding to ten times that additional time. The drop of the output voltage to the minimum value takes 18 seconds. (This value differs from the one calculated in section 3.23, since the actual anode potential is $U_A = 280$ V.) From this value, 3 seconds must be deducted for the initial time allowance t_o, so that a storage capacity of 15 seconds remains. A train running at one-sixth of the maximum speed will make full use of this time. But such low speeds should be exceptional on main lines. The limitation of the storage capacity also applies to relay storage as well as to mechanical systems.

Among the components, special attention must be paid to the valve which has a limited service life. The valve must be continually heated so that, first of all, a fracture of the heating filament must be taken into consideration. In such an event, or if the valve does not work for any other reason, there is no anode current, and relay 18 cannot be energized.

Relay 54 is energized as soon as the rail contacts *K1*, *K2* are operated. The installation thus works without warning time adaptation. By means of contact 17,2, the trouble indicator (relay 44) is cut out so that a flashlight appears at the remote supervisory post. Ageing of the valve is noticeable from the lower anode current. But as the current is lower both during the measuring period and during the retardation process, the ratio is not affected. All that can happen is a slight reduction in the time storage capacity.

5. 2. *Faults caused by the train.*

One condition for the reliable working of the warning time adapter is that the length of the measuring section is exactly one-tenth of that of the warning section. The two warning sections of one installation may be of different length, e.g. on a gradient, so that the length of the measuring sections can differ correspondingly. When mounting the rail contacts, exact adherence to the prescribed distances must be ensured.

In all the considerations so far, a constant train speed has been assumed. It will be gathered from the earlier discussion that a variable train speed will cause faults in all systems. The distances covered are no longer proportionate to the running times. A braking train is not dangerous since its mean speed in covering the warning section is lower than the speed measured on the measuring section so that the warning time is increased to an extent depending on the reduction in speed. A danger arises, however, if the speed is raised within the warning section. In that case, the train reaches the level crossing before the warning time has expired. With low initial speed and high acceleration on the warning section, it is even possible for the train to reach the level crossing before the warning signals are even switched on.

For instance, if the average speed on the warning section has increased by 10 % compared with the speed on the measuring section (in which case the speed at the level crossing will be 20 % above the speed on the measuring section), the running time needed to cover the warning section at constant speed is 10 % longer than that of the accelerated train. The difference in running times exclusively affects the warning time, as the retardation time is governed by the still low initial speed. The error therefore increases not only as a percentage of the increase in mean speed, but it also increases the more, the lower the initial

speed. If the initial speed was, e.g. 80 km/h (assuming a maximum speed of 160 km/h), the running time required to cover the warning section at constant speed is 60 seconds from which 30 seconds are deducted through the retardation. If the mean speed has been increased by 10 %, the running time is reduced to 54.5 seconds from which 30 seconds are again deducted by the retardation. The warning period has thus been reduced by 5.5 seconds. But if the initial speed was only 40 km/h where the running time at constant speed would be 120 seconds and the running time with increased speed 109 seconds, the warning period would be reduced by 11 seconds. In general terms, using the equations developed in section 2, and applying the sign t' to the values obtained with mean speeds increased by the factor x, one obtains :

$$t_a' = \frac{t_a V}{V x}$$

$$t'_{a\,\min} = t'_a - t_1 = \frac{t_a V}{V x} - (t_a - t_{a\,\min})$$

$$= \frac{t_{a\,\min} V_{\max}}{V x} - \left(\frac{t_{a\,\min} V_{\max}}{V} - t_{a\,\min}\right)$$

or

$$t'_{a\,\min} = t_{a\,\min}\left[1 - \frac{V_{\max}}{V}\left(\frac{x-1}{x}\right)\right].$$

This equation is shown graphically in figure 19. The curves below $x = 1$ show the reduced warning times encoutered if the mean speed is increased by the factor x. The curves above $x = 1$ show the increased warning time when the train is braked by the factor $1/x$. The kink at the speed ratio $V_{\max}/V = 6$ is due to the fact that, up to that ratio, the warning time adapter is able to work at a linear rate. Above that ratio, the storage capacity is exhausted. The curves show that the error is the greater, the lower the initial speed V. This is, to some extent, counteracted by the fact that slow trains (goods trains) have a smaller acceleration capacity than fast trains, e.g. railcars.

A minor deficiency of about 6 seconds is not yet dangerous since the warning period includes a safety margin of 6 seconds. Small safety margins are also inherent in the initial warning time, unless the voltage happens to be above normal, and in the measuring tolerance for long delays. A further safety factor is the proving signal. If the signal is not showing, the driver is obliged to brake, i.e. the mean speed is again reduced, and the warning time deficiency is again diminished.

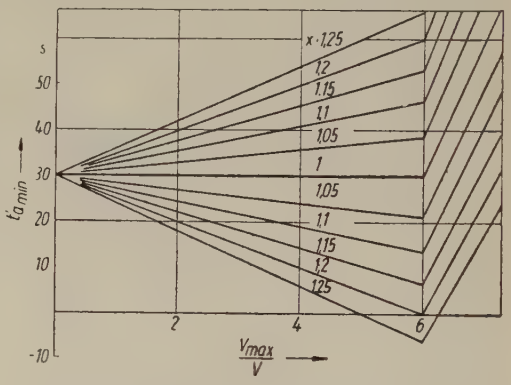


Fig. 19. — Illustrating the changes in warning times for trains with variable speed.

Even so, it is necessary to avoid acceleration on the warning section, and if possible also deceleration. If the level crossing is situated just beyond a station or signal so that scheduled accelerations occur regularly, it is necessary to forgo the warning time adapter in the direction of running. It must also be remembered that the warning time adapter must be cut out at least for one direction (disconnection of rail contact *K7* or *K8*), if a temporary speed restriction calls for the train to accelerate regularly on the warning section.

A number of schemes have become known which are designed to avoid a warning time deficiency due to train acceleration. All these schemes introduce complications and, therefore, new sources of errors and faults. In most cases, these schemes are based on the use of additional rail contacts which serve to monitor the

speed. These contacts are made operative in accordance with the method based on the choice of alternative actuating points, i.e. as a function of the measured speed. The contacts are so arranged that a train running at constant speed passes over the corresponding contact immediately after the signals have been switched on by the warning time adapter. If the train has accelerated, the signals are switched on by this contact, instead of by the warning time adapter which would only act later. With this method, the warning time is still shorter than required, though it is longer than without the additional device. The value of such an installation is doubtful. For, the same result can be obtained by forgoing the retardation-type warning time adapter and adopting, instead, the one based on the selection of alternative actuating positions. In any case, the fault with the last-named system only becomes critical at the measuring points; there is a safety margin available at all other speeds. In contrast to the retardation system, the warning time can never become zero or assume negative values.

With the retardation system, however, the measuring error can be eliminated even without additional devices, simply through shortening the measuring section by a certain value, and thus simulating a higher train speed. The calculation must be based on that train which shows the greatest difference in mean speed between measuring section and warning section. Because of the different speeds, the running times over these sections are no longer proportionate to the distances. If the measuring section is so shortened that the running time again amounts to one-tenth of the running time over the warning section, the warning time adapter will work without error, though of course only for trains with the acceleration assumed in the calculation. All trains with lower acceleration or constant speed will occasion a longer warning period which, like the shorter warning period, depends on the initial speed. Apart from the mathematical sign, the equation remains the same :

$$t'_{a\ \min} = t_{a\ \min}\left[1 = \frac{V_{\max}}{V}\left(\frac{x-1}{x}\right)\right].$$

For instance, if the measuring section is reduced by 20 %, the trains are able to increase their speed up to the level crossing by 50 % without reducing the warning period below the safety level.

A train running at, say, 80 km/h over the measuring section may increase its speed up to the level crossing by 50 %, i.e. to 120 km/h. The mean speed over the warning section will then be $x = 1.25$ times greater than the mean speed over the measuring section, i.e. 100 km/h. At constant speed, the train would require 60 seconds to cover the warning section. With the acceleration, however, this time is reduced to 48 seconds. With a normal measuring section, the warning period would be reduced by 30 seconds and would thus become too short. But if the measuring section is reduced to such an extent that the train, running at an initial speed of 80 km/h covers it in 4.8 seconds instead of 6 seconds, the warning period is only reduced by 18 seconds, and the minimum warning time is observed. The measuring section would have to be shortened by $1/x$, i.e. by 20 % in our example.

This time, the prolonged warning period for trains with constant speed can be taken from figure 19, the curves above $x = 1$ being applicable. The factor by which the measuring section concerned is shortened is $1/x$, and the permissible increase in mean speed is x. The warning period increases up to a maximum of 60 seconds. Such a prolongation of the warning period is still tolerable. On the other hand, such high accelerations on the approx. 1 km long warning section are hardly practicable so that the reduction of the measuring section, and thus also the increase in the warning period, is generally smaller.

6. Conclusion.

The last paragraph shows that the most dangerous source of errors, viz. the increase in train speeds, can be eliminated without using additional apparatus. It is therefore

possible to use the new WSSB type warning time adapter also on sections where speed increases of up to 50 % over the warning section are regularly scheduled. This contingency must of course be known beforehand, and must be taken into account in designing the installation. If regular acceleration over the warning section can only be expected as a temporary feature, e.g. because of a temporary speed restriction, it is preferable to cut out the measuring section for the time being so that the installation works without warning time adapter. In the immediate vicinity of a station, it is still preferable to forgo warning time adaptation, at least for departing trains, as the accelerations may be high. Moreover, the signal interlockings need only take into account the connecting contacts and not also, in addition, the measuring contact.

At present, a double-track half-barrier installation with a warning time adapter is in trial operation. Experience in the testing laboratory and on the line has so far been satisfactory so that it can be expected that automatic installations for the protection of level crossings, fitted with warning time adapters, will forthwith be provided in greater numbers.

Summary.

Where automatic installations for the protection of level crossings are provided on main lines with trains of different speeds, the warning periods for slow trains are considerably longer than those for fast trains. To avoid this disadvantage, so-called warning time adapters are used. Two principles on which the warning time adaptation can be based, viz. (1) selection of alternative actuating positions and (2) the imposition of a time lag, are discussed on the strength of several methods adopted in practice. The gist of the article is a detailed description of the device developed by the « Werk für Signal- und Sicherungstechnik » in Berlin-Treptow. This device, which is electronically operated and based on the time lag principle, is used in connection with the automatic half-barrier and road warning signal installations developed by the same works.

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[656 .25]

The application of ferrites to railway signalling systems,

by G. R. Cass and J. Sagues. (*)

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List of symbols.

A = Cross-sectional area of core, in cm^2.
l = Magnetic path length, in cm.
B = Flux density of the ferrites, in gauss.
$\varnothing$ = Flux = B.A.
H = Magnetising force, in œrsteds.
N = Number of turns.
E = Power source voltage.
i = Instantaneous current.
k = Proportionality constant.

1. Introduction.

An important aspect of the design philosophy of railway signalling has been the development of foolproof control mechanisms which make it impossible for a dangerous condition to be set up. Generally speaking, the signal control mechanisms are both « fail safe » and « interlocked. » The « fail safe » feature insures against component failure, while the « interlocking » feature insures against human error.

Signal control was based for many years on mechanically interlocked lever frames and mechanical actuation of the signal. During recent years, however, there has been an increasing tendency to replace the mechanical systems by electrically operated devices.

The electrical systems use electro-mechanical relays as the basic switching unit and interlocking of the relay network is readily achieved. Standard Post Office relays are thought to be quite inadequate to provide the desired degree of safety and reliability and other highly reliable relays have been developed. These incorporate large coils, heavy carbon contacts to prevent welding, large spacing between terminals and accurately aligned moving parts. Unfortunately, the cost of these relays is high and they are bulky.

This paper describes some preliminary investigations into the possible use of new electronic components for the signal control duty, the main objectives being :

(i) To ensure that the alternative switching components will satisfy the safety requirements.

(ii) To provide a less expensive and less bulky system.

(iii) To have a high degree of reliability. The new system is expected to be at least as reliable as the present relay circuits, one improvement being the elimination of moving contacts.

Thermionic valves and cold cathode tubes do not meet the required standards of safety and reliability; inter-electrode shorts may occur and the accidental removal of the bias could cause the valves to be switched on, thus giving a false indication. Solid-state devices such as transistors and semiconductor diodes have a very high degree of reliability but, similarly to valves, are subject to both open-circuit and short-circuit types of failure and hence may not be used in the signal control path; they may, however, be used in circuits, described later, where any form of failure would result in the circuits operated by them failing to safety.

(*) Imperial College of Science and Technology.

The design of switching circuits, based upon the properties of so-called « square loop » ferrites, which comply with the main objectives of this paper, has been described. It was decided to use ferrite cores exclusively in the signal control circuits because they are entirely passive elements. Transistors are used to provide a power source for the core « gates » to operate. Diodes are used in parts of the circuit which depend upon their rectification property; that is, the diodes must act as rectifiers rather than as bilateral resistors.

The scope of the work presented here is limited to an investigation of some of the possible uses of these new components in railway signalling and does not attempt to present a complete system or one that conforms to all the restrictions and refinements of railway signalling practices.

2. **Some characteristics of ferrites.**

In general, ferrites are sintered nickel-based compounds which are pressed into various shapes. The ordinary ferrites have a very high magnetic permeability and an extremely high electrical resistivity in all directions. The first property is of value in increasing the coefficient of inductance of electrical circuits. The second property means that eddy current losses are negligible, and therefore ferrites are useful at relatively high frequencies (about 1 000 times higher than the best laminated silicon steel).

Perhaps a more interesting class of ferrites for the present purpose is the so-called « square loop » class. These ferrites are similar in appearance to the ordinary type. They also have a very high resistivity, but their magnetic properties are much different. Figure 1 is a graph of flux density as a function of magnetising force for these materials. The diagram shows that the remanent flux density B_r is almost equal to the maximum flux density B_{max}. If the material is in the state which will be arbitrarily called $-B_r$, and a magnetising force H is applied to reverse the flux direction, it is seen that very little flux change takes place until H_c is reached, at which time the flux promptly reverses to the other extreme. This hysteresis effect is attributed to the particularly strong magnetic dipole of the molecules of the substance. For a thorough exposition of the physics of the phenomenon the excellent paper by Chen and Papoulis should be consulted.

If a magnetising force is applied which is not great enough to « switch » the core, then various minor hysteresis paths will be followed. Here again the remanent flux density will be almost equal to B_{max}. In

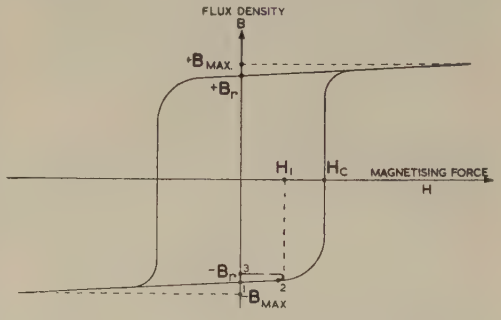

Fig. 1.

figure 1 if the core is at $-B_r$ and a magnetising force H_1 is applied and then removed, the flux will follow the path 1 - 2 - 3. The ratio of B_r to B_{max} is called the « squareness » ratio of the core and is a criterion of usefulness for applications based upon the switching properties of the core. The temperature at which the cores lose their magnetic properties is about 300° C. Square loop cores are manufactured in the form of toroids of various dimensions. For ease of winding in the laboratory one inch diameter cores have been used in preparing the signalling model components.

3. **Design of logical switching circuits. The basic circuit.**

The following electrical circuit properties of coils wound on square loop ferrites are used as the basis of design for the new system :

(i) A small flux change, as occurs when the core flux moves along the line $-B_r$

to $-B_{max}$ or $+B_r$ to $+B_{max}$ will produce only a very small voltage on any of the linking windings. If, however, the flux change is from $-B_r$ to $+B_{max}$ or from $+B_r$ to $-B_{max}$, then a relatively large voltage will be produced. This follows from Faraday's Law of Induction.

(ii) The cores are current defining devices, that is, so long as saturation is not reached, they will allow only a constant value of current i_c to flow through the winding, regardless of the voltage applied. The current i_c corresponds to the magnetising force H_c in figure 1.

(iii) If less current than i_c is forced through, the core flux will not move around the B — H loop. From property (i) it can be seen, that in such a case, very little voltage will be developed on any other winding. The last two properties will now be proved.

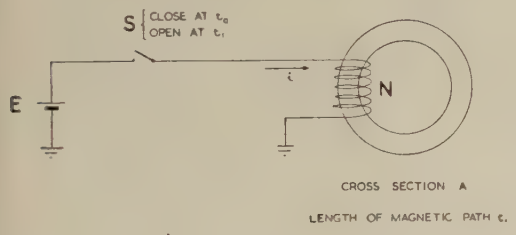

Fig. 2.

In figure 2, we have a toroid of square loop material with a cross-section A, and a magnetic path of length l. The core is wound with N turns. The coil is connected to a switch which completes the circuit to a battery of voltage E. The switch closes at time t_0 and opens at time t_1, and a current i passes through the coil for the interval $t_1 - t_0$. We shall find it useful to derive a relationship among these quantities. We may assume that the flux in the core is normally at $-B_r$, and that the current is in such a direction as to reverse the flux to $+B_{max}$. Figure 1 is a plot of flux density as a function of magnetising force. By replotting the graph to find magnetising force as a function of flux density, and idealising the curve somewhat, figure 3 is obtained. Then :

$$-B_r \leqslant B \leqslant B_1 \text{ for } o \leqslant H \leqslant H_1 \qquad (1)$$

and $B_1 < B < +B_{max}$ for $H_1 < H$.

From Faraday's Law we have,

$$\Delta\varnothing = \frac{1}{N}\int_{t_0}^{t_1} e.\ dt. \times 10^8 \qquad (2)$$

where $\Delta\varnothing$ is the change of flux and e is the voltage applied.

If e is constant, as in the case of figure 2, and equal to E, then equation (2) can be written as :

$$\Delta\varnothing = \frac{E}{N} \cdot (t_1 - t_0) \times 10^8 \qquad (3)$$

or

$$\Delta B \cdot A = \frac{E}{N} \Delta t \times 10^8 \qquad (4)$$

then

$$E \cdot \Delta t = \Delta B \cdot A \cdot N \cdot 10^{-8} \qquad (5)$$

The maximum value of the r.h.s. of equation (5) is approximately :

$2B_r A \cdot N \cdot 10^{-8}$, as can be seen from figure 3.

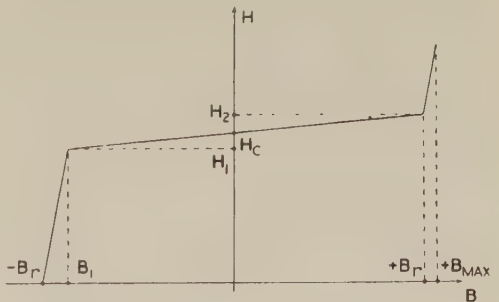

Fig. 3.

Thus the core can support a counter e.m.f. for a certain interval, and during this interval does not require the magnetising force to be greater than H_2.

Since $H = \frac{N \cdot i}{lk}$ where k is a proportionality constant,

$$i = \frac{H}{N} lk \qquad (6)$$

We have seen that if the voltage — time product is less than a certain maximum, then H need never be greater than H_2 and consequently from equation (6)

$$i_{max} < \frac{H_2 \, l \cdot k}{N} \qquad (7)$$

Since practically no flux change takes place for H less than H_1, we can say that :

$$i_{min} \geqslant \frac{H_1 \cdot l \cdot k}{N} \qquad (8)$$

For ease of design we can say that if the product (or integral) of applied volts and time is less than a certain constant maximum value, for a given core, then the current that will flow in the circuit will be constant and equal to :

$$\frac{H_c \cdot l \cdot k}{N}$$

It is apparent that if less than i_c flows through a core winding very little flux change will result. This is easily seen in figure 1. A current, corresponding to H_1, is applied and reversed. The flux follows the path 1-2-3 as described previously. The flux change along the ordinate is seen to be very small compared with the size of the B-H loop. Since the flux change is small, then from Faraday's Law, the voltage developed is also small.

It should be noted here that the cores are not used as bistable devices whose two stable states are $+ B_r$ and $- B_r$.

4. The application of the basic circuit to failsafe « gates », amplifiers and « bistable » units.

(i) « *Gates* »

Using the three relations derived in the last section we are now in a position to construct a two input « and » gate. This is simply a device with two inputs and one output; both inputs must be energised at the same time to get an output. Figure 4 shows such a circuit. Core 1 has two windings of N turns with relative polarities as shown.(*) Points A and B are the two input terminals with respect to earth. Here and throughout the rest of the paper a 30 kc/s square wave of 20 volts amplitude has been adopted as the power source. The reasons for this voltage form will be given subsequently. This voltage will be referred to simply as E

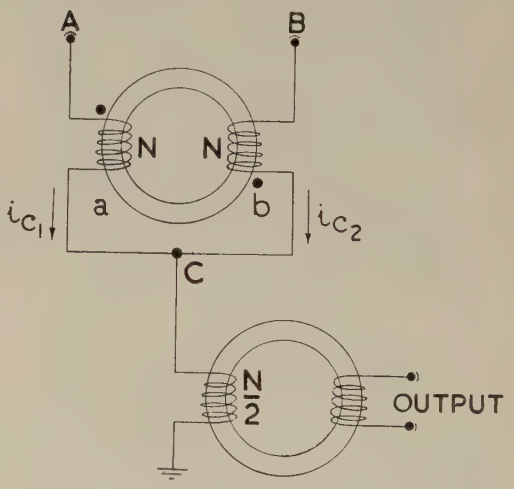

Fig. 4. — « And » Gate.

(meaning the instantaneous bus voltage). Then, if E is applied to point A, and point B left uncompleted, a current i_{c1} will flow through coil « a » down to the $\frac{N}{2}$ winding of core 2. Since i_{c1} will correspond to H_c for core 1, this core will cycle around its BH loop; but i_{c1} is exactly half the necessary current required to cycle core 2 since it has $\frac{N}{2}$ turns. Since core 2 does not cycle, no output voltage will be developed on its

(*) The dotted terminal convention is used, that is « currents into dotted terminals cause fluxes that add », or alternatively, « dotted terminals have the same instantaneous polarity ».

output winding. If now point B is connected to E, then core 1 will stop cycling since the two input currents are in opposite senses, thus causing no net magnetising force in the core. Therefore core 2 will cycle, since point C is at E, and an output will result.

In this type of gate the input terminals (A and B) are either connected to E or open circuited. This is not always possible in practice and so a gate whose input terminals are either E or O volts is useful. In figure 5, if point A is at E and point B at earth, then i_{c1} flows into the winding of core 3. This is insufficient to cycle it, hence there is no output voltage. If now, point B is raised to E, an additional current i_{c2} is available.

The sum of $i_{c1} + i_{c2}$ is just sufficient to cycle core 3, giving an output.

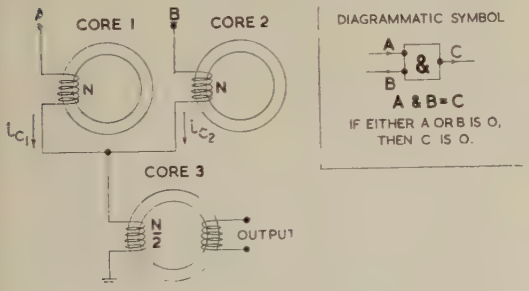

Fig. 5. — « And » Gate.

The output of a two-input « And gate » can be fed into another such gate and thus an « And gate » of any number of inputs can be built up.

(ii) *Amplifiers*

The voltage wave form degenerates after passing through several gates and it is necessary to regenerate it occasionally. For this purpose a regenerative or amplifier circuit is necessary. Figure 6 shows the circuit of such an amplifier. Cores 1 and 2 are connected in such a way that there is no net voltage around the loop composed of the « a » coils, i.e., the control circuit. Core 3 will thus have only half current flowing into the winding. Core 4 is an input transformer and core 5 is a series inductance to filter out switching transients. The diode and condenser impose an average D.C. current in the control loop if there is a signal present at the input terminal. This D.C.

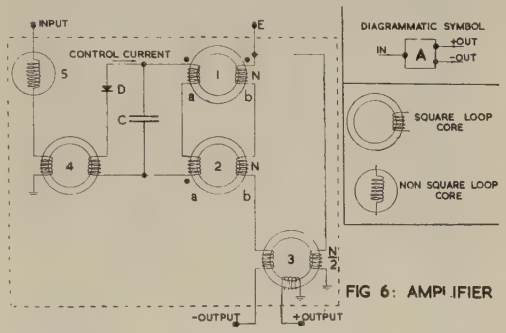

Fig. 6.

control current will saturate cores 1 and 2 and core 3 will then receive the full bus voltage and develop an output at the terminal marked « Out ». The extra winding on core 3 is a so-called « negation » output. With no input voltage at the input terminal core 3 will not cycle, therefore no voltage will be developed across any of its windings, thus the terminal marked « — ve out » will be at E by conduction through the coil up to the bus. When an input voltage is applied, core 3 is cycled, a voltage equal to E is developed across each of its windings and the potential at « — ve out » disappears because of the relative polarities of the coils.

This outline is quite standard magnetic amplifier practice except for one very important feature. The square loop output core gives the amplifier a threshold characteristic. For no input there is no output. As the input voltage is increased the output stays at zero until a certain threshold is reached, thereafter the output goes up very rapidly. The threshold input level can be designed to have a large range of values. The threshold effect means that amplifiers can be cascaded without an accumulative « leak-on » effect. Typical amplifiers have the following characteristics : Input 20 volts at 15 mA giving an output of approximately 20 volts at 150 to 200 mA.

(iii) *Bistable units*

The threshold effect mentioned in the last section enables the modification of the amplifier circuit to a bistable unit, that is, a unit whose output is normally zero, but if turned on, will remain on. This unit is analogous to a relay which when picked up holds itself.

Figure 7 shows such a circuit. The output is normally zero. If a voltage is applied at the terminal marked « Trigger », the output becomes equal to the bus voltage (E). The output remains E when the trigger voltage is removed, and until the bus voltage is interrupted. Thereafter it remains zero until re-triggered.

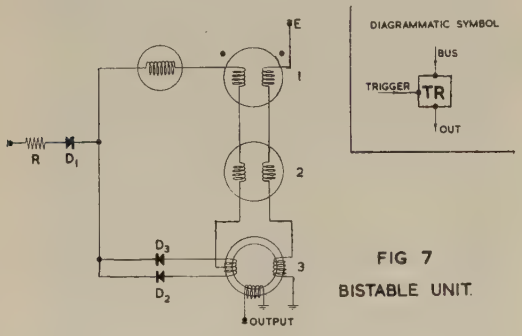

FIG 7
BISTABLE UNIT.

Fig. 7.

(iv) *Inhibiting gate*

It is sometimes necessary to simulate the normally closed or « back » contacts on a relay. The unit of figure 8, when connected to the negation output of an amplifier, is used for this purpose. The gate itself is similar to the amplifier circuit except that it has no output coil. It does not have an output voltage of its own, but rather acts as a variable impedance between its output and input terminals. Normally with no voltage applied at the terminal marked « control », there is approximately 400 ohms impedance between « input » and « output » terminals. With a voltage applied at the control terminal the transfer impedance drops to approximately 5 to 10 ohms. These values of impedance are typical of the present circuits; these circuits can be designed to give other values if required. It was explained in a previous section that the negation output of an amplifier is zero if the amplifier is « on », and E if the amplifier is « off ». Thus in figure 8, with a signal

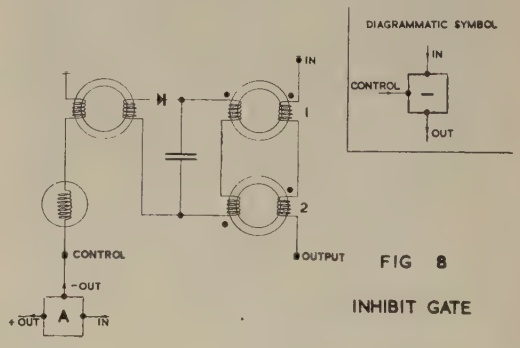

FIG 8
INHIBIT GATE

Fig. 8.

into the amplifier, its + ve output terminal is at E volts, its — ve terminal is at zero, hence the control terminal of the Inhibiting gate is at zero and the gate is in its « closed » or high impedance state. With no input to the amplifier the Inhibiting gate is open. If the wire connecting the amplifier and the Inhibiting gate opens for any reason, it is seen that the Inhibiting gate will revert to its high impedance or « closed » state.

(v) *Some aspects of the « fail-safe » features of these circuits*

All the circuits described so far have one thing in common, namely, if the circuit is opened at any point the result will be the loss of output voltage. In the gate circuits this can be readily appreciated because of extreme simplicity of these circuits. The amplifier circuit has two other components in it, a diode and a condenser, and the result of failure in these components on the amplifier circuit as a whole may not be entirely obvious. From figure 6, in order for cores 1 and 2 to pass enough current to core 3 to cause it to develop an output voltage, they must have an average D.C. current flowing in the « a » coils, or control circuit.

An A.C. current flowing in the control circuit results in no output. Thus if the diode « opens », there will be no current in the control loop, and hence no output voltage. If the diode « shorts », there will be A.C. current in the control loop and hence again, no output voltage. If the condenser « shorts », there will be no control voltage. If the condenser « opens », the magnitude of the D.C. current in the control loop will be so reduced that the amplifier will have either no output whatever, or a very small output when it would otherwise be « on » fully. The diode and condenser do not occur indiscriminately in the circuits but only in the way just described. The same arguments apply also in the case of the bistable unit and inhibiting gate.

In general, it can be said that all forms of circuit failure are safe except an insulation failure in some coils. Several suggestions for rendering insulation failure less of an objection are considered later.

(vi) *An example of the realisation of a simple switching function.*

The design of the various gates, amplifiers and bistable units which, when connected together according to some design procedure, will controll the signals, has been discussed. The logical design of such a system is best shown by taking a simple switching function as an illustration. A simple route consisting of two sections of track only will be considered (see fig. 9).

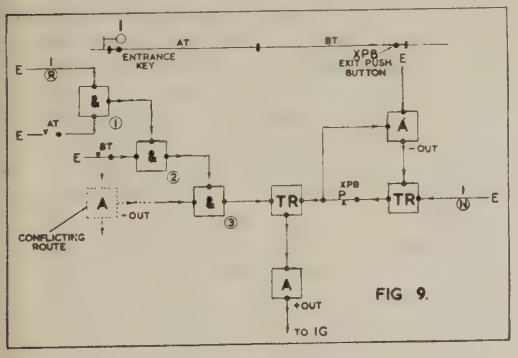

Fig. 9.

If the two sections of track are unoccupied, the route may be set up by turning the entrance key and pushing the exit button. To make this illustration more complete, it will be assumed that the signal will be cleared only if an associated route, not shown here, is in the normal « not called » position.

The system must have at least two gates which will « open », that is, allow power to go through when the track circuits are clear, and an « inhibit » (or negation) gate which will open in the presence of a signal from the associated route showing that it is normal. All three gates require a signal to be present before they will open; this is in accordance with the usual safety precautions which require that a disconnected wire shall produce the same effect as a condition closing the gates.

The Route Trigger is a bistable unit which remembers that the exit button has been pushed, that is, that the route has been called, and will allow power to go through the rest of the circuit if the above conditions (labelled 1, 2 and 3 in fig. 9) are satisfied.

If the route cannot be set up due to one or more of the safety conditions not being satisfied, or if, after the signal has cleared it is returned to normal by the passage of a train, the signalman is required to restore the entrance key before he can call the route again; the operation of the exit button alone should not clear the signal. This condition is satisfied by the bistable unit called in the diagram the « Button Trigger». This unit will interrupt the power to the exit button once the button has been pushed, regardless of whether the route has been obtained or not. The trigger is fed from the « — ve output » terminal of an amplifier unit; that is, power is supplied to the trigger when the amplifier is off. The trigger is turned on by means of the normal contacts of the entrance key, and will remain on irrespective of the position of the entrance key. Power is now available at the exit button. On turning the key and operating the exit button, the Route Trigger will or will not come on depending on whether the conditions 1, 2 and 3 are satisfied or not; at the same time, the amp-

lifier is turned on; thus there is no power at the «— ve output » terminal and the «Button Trigger » is turned off, interrupting the power to the exit button. This switches off the amplifier and restores the power to the trigger, which remains off until the restoration of the entrance key. In other words, the operation of the exit button causes the power to it to be interrupted regardless of the state of the Route Trigger, until the entrance key has been restored.

This unit is not « fail-safe » since disconnecting the lead from the exit button to the amplifier would result in the power to the exit button not being interrupted on operation of the exit button. However, this does not affect the safety of the circuit as a whole, since the necessity to restore the entrance key once the exit button has been pushed is dictated by convention and not by safety considerations.

The amplifier increases the power available to the value required to operate the signal lamps. The negative output from the amplifier unit is used to operate the « inhibit » gate of the associated route. This output is present only when the amplifier itself is producing no output, that is, when the route is not set.

Thus it can be seen that this « logical » switch system simulates exactly the behaviour of relay systems.

5. Block diagram of a simple rail-junction model.

It was decided to instrument a model of a double track junction, the symbolic diagram of which is shown in figure 10. Several of

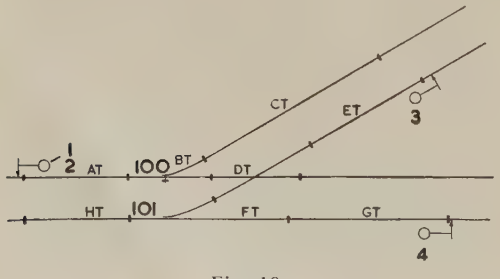

Fig. 10.

the refinements usually found in standard signalling practice (route-locking, for instance) have been left out of this model for purposes of simplification. It must be emphasised, however, that these omissions do not imply any inherent limitations of the circuit approach presented. In fact, at this stage of the investigations, no reason has been found to prevent these new circuits from performing all the functions of the present relay system. It is felt that the existing model is sufficiently complex to demonstrate the possibilities of the system.

Figure 11 shows a block diagram of the circuits involved. The diagram is somewhat simplified to facilitate its interpretation. Several design short-cuts have been used in the development of the circuits since all units are not yet compatible. The achievement of compatibility between all units will require more circuit development. Relays have been used to start the model point machine motors. These relays are analogous to the contactors in present point machines.

The power source generator is shown as the box marked « Generator ». It consists of several power transistors in a saturation controlled oscillator followed by current amplifiers. The output transistors act as switches making and breaking the connection from the output terminal of the generator to a D.C. source. This is a « fail-safe » circuit since failure of a transistor will inevitably result in no output from the generator which is transformer coupled to the bus. The basic repetition rate is 30 kilocycles per second. This frequency was chosen by consideration of equation (5), $\Delta\varnothing$ being fixed by the physical size of the core. E was chosen as 20 V, and 50 turns as the smallest number of turns on any core (to limit heat dissipation). From this, the period Δt is obtained, and can be related to frequency.

A typical route, route 3 in figure 11, will now be considered in detail. With the entrance key in the normal or « off » position and the exit button released, power is available at the « Button Trigger » which is switched on by the normal contacts of

the key. On operating the key, the « Button Trigger » remains on, and, if track relays E, D, F and H, are energised the bus voltage proceeds through the E, D, F and H gates. Then, with points 100 reversed, the bus voltage passes through the corresponding gate. If the points are normal and their track-locking track is unoccupied, an alternative path is established by gates « B » and « 100 NW ». The two inhibiting gates then follow. These gates will only be open if routes 2 and 4 are not set. This is « fail-safe » since an opening of the connection to the « control » terminal will close the gates, as described previously. Power is now available at the input of the Route Trigger which may be switched on by pressing the exit button. This action also causes the Button Trigger to be switched off, via its amplifier, thus interrupting the power to the button. The Route Trigger controls the amplifier which provides an inhibiting condition for routes 2 and 4, and an output to actuate the signal. That is, following down from the «+ ve output » terminal of the amplifier, if points 100 and 101 are normal, they will be reversed. The power can then proceed through the two gates « 100RW » and « 101RW » to the signal light.

The Route Trigger is holding through all the necessary gates. Interruption at any point will turn it off and a new route setting will be required. This can only be obtained by first resetting the key, since no power is available at the exit button until this is done.

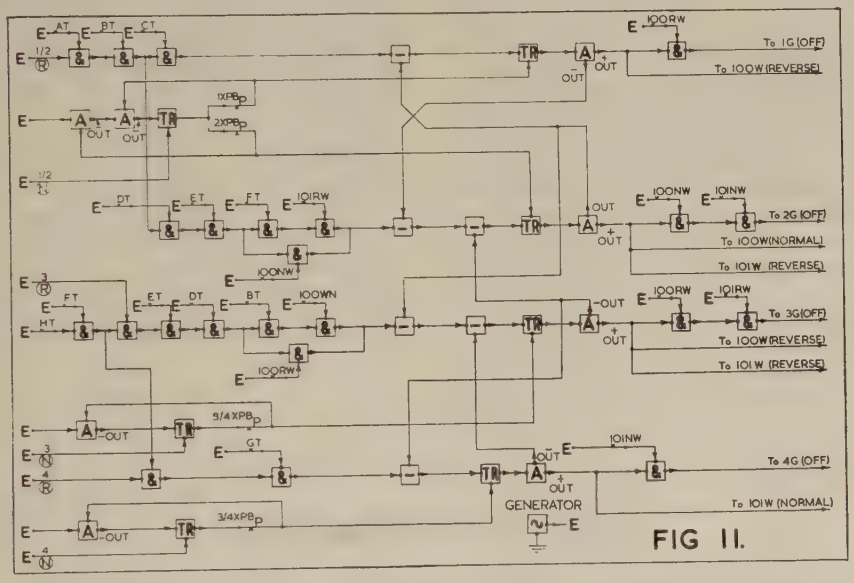

Fig. 11.

6. **Conclusions.**

The preceding circuits do not solve all the problems encountered in railway signalling. Such refinements as approach control and locking and timing circuits have not been included. However, it can be said that their inclusion would not present a major problem. The work has in fact shown that a system as safe as and in all probability more reliable than the present electromechanical relay system can be designed at a cost remarkably lower than the relay systems. Preliminary estimates would indicate a reduction in cost by a factor of the order of ten.

One-inch diameter cores were chosen for ease of winding in the laboratory. One of the first improvements that come to mind is a reduction in core size. This measure, together with an increase in the power source frequency would lead to a more efficient system and to the need for less turns in the coils. It is conceivable that the number of turns would be so small that each turn would be physically separated from its neighbour, thus eliminating insulation problems. « Potting » the units in resin would render them entirely weatherproof and shockproof.

The design of entirely compatible units, that is, units that could be connected together indiscriminately, would be the next step. At present, the amplifier unit is the only one that is entirely compatible, that is, it can have any other unit as input or output.

Finally, to facilitate wiring and reduce wiring costs, the design of the basic circuits as « plug in » units seems to be indicated.

7. Acknowledgements.

The present investigation has been carried out in close collaboration with the British Transport Commission who placed a contract with the Electrical Engineering Department of Imperial College for the necessary equipment required. The Authors wish to acknowledge the considerable help, especially in connection with the statement of the railway signalling problem, which they have received from Mr. Woodbridge and his staff. Many thanks are due also to Professor A. Porter and Dr. A. R. Boothroyd of Imperial College for many hours of constructive discussion.

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[656 .225 (73)]

Piggyback Parade.

New progress. — New plans. — New problems,

by Nancy FORD.

Condensed from « Modern Railroads », February 1959).

The transport of trailers and semi-trailers on flat wagons is growing in the U.S.A. and Canada. Although the total tonnage was reduced by 14.9 % from 1957 to 1958, the number of wagons loaded with semi-trailers increased during the same period from 249 065 (for 40 railways) to 276 767 (for 41 railways), or about 11.1 %. There are already 49 railways in the U.S.A. offering this service (see Table I) but several other railways have already announced their intention of introducing it very shortly (Chesapeake & Ohio, Illinois Central, Boston & Maine, etc.).

This transport is offered with the variants shown as Plans I to V (see Table II). Plans III and IV were recently introduced for long runs, in an attempt to regain for the railway traffic which is being lost to an ever increasing extent to semi-trailers belonging to the actual consignors. The new rates were promptly accepted, though some of

them give rise to enquiries started by the I.C.C.

Other developments have been made public. For example an agreement has been made between the Rock Island Company and the Consolidated Freightways (the largest road transport company), an agreement which in fact lets each partner in on the clientele of the other. This agreement will have far wider reaching consequences than those formerly signed between the Chicago & Eastern Illinois and Kansas City with local transport firms.

The trains transporting the semi-trailers have been speeded up by several railways linking up the West Coast to Chicago; savings of 24 hours have brought the times of many trains down to 62 or 63 hours. New lines have been opened to this service.

At the same time the railways have continued their trials of various systems (see Table II). An interesting development has been the adoption of the Flexi-Van by the Chicago & Milwaukee, a system used to date only by the New York Central. Agreements have also been made by the Chicago, Burlington & Quincy. But the lack of standardisation remains one of the major defects of the system.

Certain railways consider that they should continue to assure these services with the variety of equipment now in use for fear of loosing an important part of the traffic. Stress has however been laid on the need for the railways to form equipment pools (wagons, semi-trailers, containers).

Other railways, not wishing to purchase stock which will soon be out of date, would like general regulations to be introduced for the exchange of such stock between railways. Some of them, pointing out the high dead weight compared with the useful load, insist on the need to build lighter wagons and semi-trailers, as well as to reduce the cost of loading and unloading.

TABLE I.

THESE ARE THE PLANS.

Plan I. — Carriage by railroad of trailers of common carrier truckers either at a flat charge per trailer or a so-called « division » of the rate-a « substituted » service performed for the trucker, who solicits the business and bills the shipper. Also see Plan V.

Plan II. — Railroad performs all of the service, including furnishing of trailer, loading and unloading, and pickup and delivery. Railroad solicits the business at truck-competitive rates and bills the shipper.

Plan III. — Railroad furnishes flatcar and provides loading and unloading of trailers. Shippers handle pickup and delivery. Ramp-to-ramp rates made for these shipper trailers based on commodity and quantity moved, or at a flat per-trailer charge. (Plan III charges usually approximate 50 cents a car-mile when two trailers are loaded).

Plan IV. — Railroad furnishes only power and rails for shippers who not only furnish both flatcar and trailers, but perform all loading, unloading, and pickup and delivery services. A flat charge per car is made for not exceeding two trailers, and whether trailers are loaded or empty. (Plan IV charges usually approximate 40 to 42 cents a mile.)

Plan V. — Joint rail-truck rates. In effect, such rates extend the territory of each carrier into that served by the other, permitting each to handle shipments originating in or destined to the other's territory. Each may sell for the other.

Note : There are a host of variations of these basic plans. Under Plan II, for example, there are special rates which require shipper to load, consignee to unload. Other rates restrict the terminal area; still others apply only when shipper picks up the empty trailer at the ramp and delivers the loaded trailer at the same location. In many cases, allowances are made for use of shippers' trailers — and so on.

TABLE II.

THE « HOW » OF PIGGYBACK.

Although piggyback service is essentially the hauling of highway trailer bodies, whith or without wheels, atop railroad flatcars, a wide variety of loading and unloading methods and, consequently, of equipment, has grown up with the new operation.

This experimenting is necessary and is bound to continue, but railroaders agree that more standardization must come, to facilitate interchange and to keep investment in special facilities at a reasonable level. Many roads are turning to leasing arrangements (and so are shippers under Plans III and IV) as a means of keeping equipment costs down.

Here, in brief, are chief loading methods in use, and equipment involved :

1. Conventional end-loading on conventional flatcars converted to or built for piggyback service. Several simple, fast-working « hitch » and « tie-down » devices have been developed for and are in use on these flats.

Trailer Train Co. — owned by ten railroads, U.S. Freight Co. and Rail-Trailer Co., is increasing its fleet of flatcars for lease to member roads to 1916 by the addition of 800 85-ft cars built by ACF and Pullman-Standard. Van Car Co., a subsidiary of Rail-Trailer, handles car distribution. Rail-Trailer also has a fleet of 760 trailers (built by Fruehauf and Trailmobile) for lease under Plans I, II and III.

2. Flexi-Van system : Employs special turntable flatcars and highway bogies to transport trailer containers without wheel assemblies. Until recently limited to New York Central, the system has been adopted by the Milwaukee, and the « Q » is now interchanging vans but not cars with Central.

3. Clejan system : This « guided » end-loading method requires special center-sill flatcars and special devices on trailers. Some 450 cars are in use on SP, Erie, KCS, and New Haven. (SP, a big user, offers a discount in charges to common carrier truckers whose equipment has Clejan attachments.)

This system got a big push when General American Transportation Co. (largest of specialized-car operators) bought American patent rights on the Clejan car. GATX has leased 100 of these flatcars to freight forwarders and is building 150 new, improved lightweight flats for the service. GATX also licensed Fruehauf to build and sell trailers and multi-purpose containers newly designed for transport on GATX cars.

4. MoPac « Container » system : In side loading, demountable trailers are swung to and from gondolas and flats by gantry cranes.

5. Adapto system was developed by ACF, and has a wide variety of general and special-purpose containers. These also are lifted to and from flatcar or flatbed truck. On the Rock Island, where the method is in limited use, special Clark fork-lift trucks handle the transfer.

Container developments are bound to make piggyback head-lines as more and more experiments are tried. Southern Car & Mfg. Co. recently brought out a « Railiner » container using special roller arms for side transfer between flat and truck. Fruehauf's Strick Division has developed « Stricktainer, » a 17 ½-ft body with an adjustable trailer chassis to handle one or two units. Pullman, Inc., which some time ago announced its « PAT » system, recently made Arthur L. BERRY, formerly General Manager of Trailer Train, Assistant to the President, with the specific assignment of advancing and coordinating efforts of Pullman-Standard and Trailmobile in the development of trailers, containers, and flats for coordinated piggyback services.

[385 (06 .111]

OFFICIAL INFORMATION

ISSUED BY THE

PERMANENT COMMISSION

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International Railway Congress Association.

FINAL SUMMARIES

adopted at the Enlarged Meeting of the Permanent Commission of the International Railway Congress Association. (New Delhi, December 1959).

SECTION II. — Locomotives and rolling stock.

QUESTION 2.

Problems met in the design of multi-current rolling stock. Existing types : experimental results. Future developments.

SUMMARIES.

1. Multi-current motive power units are power units which can work with more than one type of current.

   Such units are already in operation, or under construction, in the following combinations :

   a) D.C. systems of different voltages;

   b) A.C. systems of different voltages but the same frequency;

   c) A.C. systems of different voltages and frequencies;

   d) one or more A.C. systems and one or more D.C. systems;

   e) one three-phase current system and one D.C. system.

2. Multi-current motive power units for D.C. systems of different voltages are characterized by the following features :

   a) Compared with motive power

units exclusively designed for the highest voltage concerned :

— there must be a possibility of providing supplementary combinations for the traction motors;

— there must be a possibility of connecting the auxiliaries, inasmuch as they are fed from the catenary, in parallel instead of in series, which may call either for a division of the auxiliary power, or for the use of motors with two collectors;

b) Compared with motive power units exclusively designed for the lowest voltage concerned :

in addition to the features mentioned under *a*), it is necessary to provide the traction motors, the high-tension cabling and those auxiliaries fed directly from the catenary with an insulation adequate for the highest voltage.

The use of the full power of the multi-current power unit at all the voltages is only possible if these voltages are whole multiples of the motor voltage.

3. Multi-current motive power units for A.C. systems of different voltages but the same frequency are characterized by the following features :

a) Compared with motive power units exclusively designed for the highest voltage concerned :

it is necessary to adapt the transformer primary :

— either by dividing the primary winding into groups and connecting these in parallel instead of in series;

— or by means of a tapping on the primary circuit, so arranged that the secondary voltage remains the same.

If it is desired to have the full power available at both voltages, the former method is only applied if the highest voltage is a whole multiple of the lowest voltage. With the second method, on the other hand, it is always possible to obtain the desired tapping provided that the primary windings are suitably reinforced.

Moreover, the second method permits of speed regulation on the high-tension side;

b) Compared with motive power units exclusively designed for the lowest voltage concerned :

in addition to the features mentioned under *a*), it is necessary to provide the transformer primary, the pantographs, the circuit breaker and the cabling between these components with an insulation adequate for the highest voltage.

4. Multi-current motive power units for A.C. systems of different voltages and frequencies may be equipped :

a) either with A.C. motors;

b) or with undulating current motors.

In the former case (A.C. motors), the multi-current motive power units are characterized by the following features :

a 1) Compared with motive power units exclusively designed for the highest voltage and frequency concerned, it is necessary :

as far as the transformer is concerned :

— to enlarge the copper cross-section of the primary windings;

— to enlarge the section of the magnetic core;

— to provide switch-over facilities for the tertiary windings used for current supply to the auxiliaries;

as far as the traction motors are concerned :

— to provide for the possibility of modifying the degree of interpole shunting;

a 2) Compared with motive power units exclusively designed for the lowest voltage and frequency concerned, it is necessary :

as far as the transformer is concerned :

— to insulate the primary for the highest voltage;

— to subdivise the windings to a greater extent in order to reduce the leakage at the highest frequency;

— to provide switch-over facilities for the tertiary transformer winding;

as far as the traction motors are concerned :

— to use traction motors designed for working at the highest frequency;

— to provide for the possibility of modifying the degree of interpole shunting;

In the second case (undulating current motors) the multi-current motive power units are characterized by the following features :

b 1) Compared with motive power units exclusively designed for the highest voltage and frequency concerned, it is necessary :

as far as the transformer is concerned, and besides the particularities mentioned under *a* 1) for the transformer:

— to increase the dimensions of the transformer in order to take into account the feeding of the motors through rectifiers; this increase is moreover function of the rectifiers combination;

as far as the traction motors are concerned :

— to give up A.C. traction motors, in the less frequent case when the power unit at the highest frequency was fitted with this type of motor;

b 2) Compared with motive power units exclusively designed for

the lowest voltage and frequency concerned (and equipped with A.C. traction motors), it is necessary :

as far as the transformer is concerned, and besides the particularities mentioned under *a* 2) for the transformer :

— to increase the dimensions of the transformer in order to take into account the feeding of the motors through rectifiers; this increase is moreover function of the rectifiers combination;

as far as the traction motors are concerned :

— to give up the A.C. traction motors in the most frequent case when the power unit at the lowest frequency and the lowest voltage was fitted with this type of motor;

— to introduce rectifiers in the equipment.

5. Multi-current motive power units for one or more A.C. systems and one or more D.C. systems are most frequently equipped with rectifiers.

On A.C. systems the speed can be controlled :

— on the A.C. side;

— on the D.C. side;

— at the rectifiers, if they permit it.

Speed regulation on the A.C. side or at the rectifiers gives rise to additional complication of the equipment.

D.C. regulation increases the energy consumption to an extent which is moreover variable with the nature of the service.

Multi-current motive power units of this category are characterized by the following features :

a) Compared with motive power units exclusively designed for A.C. of the highest voltage and frequency concerned :

in addition to the features listed under *b* 1) of Summary No. 4, it is necessary;

— to adopt construction devices permitting speed regulation on D.C. lines;

— to use D.C. traction motors whose insulation adapted to the highest D.C. voltage to be taken into account must be reinforced compared with A.C. motors;

— to install appropriate circuit breakers and starting resistances equipped with the necessary contactors;

— to use auxiliaries which, inasmuch as they are also required for D.C. working, must be designed for D.C. and must, on A.C. lines, be fed through rectifiers.

The elimination of speed control on the A.C. side or at the rectifiers may also be envisaged;

b) Compared with motive power units exclusively designed for A.C. of the lowest voltage and frequency concerned :

— most frequent use of rectifier equipment;

— increase of the size of the transformer, as mentioned in Summary No. 4.

In addition, when working on D.C. lines, these motive power units must have the same features as under *a*) above;

c) Compared with motive power units exclusively designed for D.C. of the highest voltage concerned, it is necessary :

— when working on D.C. lines, to rely on the same measures as those listed in Summary No. 2, letter *a*);

— when working on A.C. lines, to install a transformer, a circuit breaker and rectifiers to feed the traction circuits and auxiliaries;

d) Compared with motive power units exclusively designed for D.C. of the lowest voltage concerned, it is necessary :

— when working on D.C. lines, to rely on the same measures as those listed in Summary No. 2, letter *b*);

— when working on A.C. lines, to rely on the same measures as those listed under *c*) above.

6. In the only reported case of D.C. motive power units which must also work with three-phase current, a three-phase transformer and rectifiers have been provided; those permit the working of the traction motors and auxiliaries on A.C. lines, without any alteration.

7. To enable motive power units to work on lines with different types of current, they may have to be equipped with one or more additional pantographs, depending on the networks on which they are to run, unless the dimensions of the collector bow and the performances can be completely standardized.

8. It is desirable to provide, on multi-current motive power units, either a protection device preventing the connection of the feeding system to a wrong traction coupling or a wholly automatic traction equipment selection device.

9. In all cases, where it is not necessary to obtain the full power with all the types of current concerned, the various conditions outlined above may be relaxed or even ignored, and other solutions might also be adopted.

10. Multi-current motive power units are more complicated, and therefore more costly, than motive power units designed for one type of current only.

Therefore, the numbers of such vehicles for which orders are placed, are normally limited to the number needed and remain small; this fact tends to increase the price still further.

11. Owing to their complexity, the cost of maintaining the electrical parts of multi-current motive power units is

higher than with units designed for one type of current only. This applied the more, the greater the number of different types of current for which the unit is designed.

However, as the total maintenance cost is largely governed by the maintenance of the mechanical parts, an increase in the cost of maintaining the electrical parts will not have a major incidence on the total maintenance cost.

12. In view of the fact that the first cost and maintenance cost of multi-current motive power units are higher than those of units designed for one type of current only, preference should be given to the alternative solution of changing locomotives at the transition station, wherever this solution is compatible with operating conditions.

13. Where the change of motive power units is not compatible with operating conditions, e.g. because :

— the transition stations are complicated, or

— it is desired to work through trains without changing locomotives, or

— it is desired to obviate the need for passengers to change from one railcar or multiple-unit train to another, or

— it is necessary to have regard to the shunting movements at stations equipped for more than one type of current;

multi-current motive power units must be used.

The technical feasibility is demonstrated by vehicles already in service.

14. If operating requirements permits, it is advisable, for economic reasons, to design the multi-current motive power units with one type of current working at reduced power.

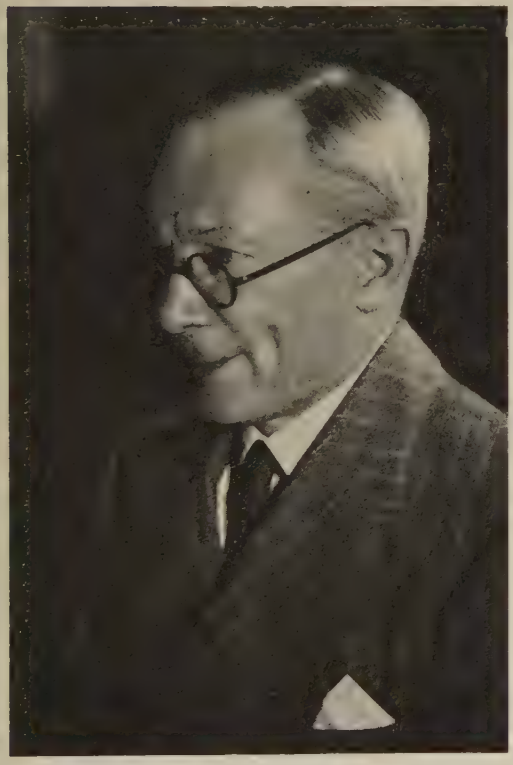
This solution is acceptable if the working of the motive power units is confined to short runs over the transition points, to reach the station of the adjoining railway system equipped with one type of current only.

OBITUARY.

Sir William WOOD,

Former President of the London Midland and Scottish Railway.

Former Member of the Permanent Commission of the International Railway Congress Association.



We have learnt with deep regret the death on August 27 last, of our Colleague Sir William Wood, who was a former member of the Permanent Commission of our Association.

Sir William Wood was born at Belfast on February 14, 1883. He was educated at the Methodist College, Belfast, and at the age of 15 joined the accountant's department of the former Belfast and Northern Counties Railway. When the Government took control of the Irish Railways in 1917, he was appointed secretary and later a member of the railway accountants committee set up by the Irish Railway Executive Committee. In 1919, when the Ministry of Transport was formed, he was transferred to London as Director of Transport (accounting).

Later, in 1924, he returned to the railway service as assistant to the accountant-general of the L.M.S.; he became controller of costs and statistics in 1927 and three years later he was appointed Vice-President of that railway.

Sir William Wood was created a Knight Bachelor in 1937 for his services to transport. When the war came in 1939, he was nominated member of the Railway Executive Committee and in 1941 he succeeded to Lord Stamp as President of the L.M.S. Railway, taking over the burden of supreme executive responsibility, in addition to his duties as a member of the Railway Executive Committee. In 1947, he was created K.B.E. In August 1947, two days after the Transport Act became law, he was appointed a full-time member of the British Transport Commission. He retired in 1953.

SIR WILLIAM WOOD was a Member of our Permanent Commission and of our Executive Committee from February 1946 to February 1948. In spite of his many activities, he was very devoted to the works of our Association. Always pleased to help with all his experience and knowledge in any occasion, he distinguished himself by his clear sightedness, logic and competence and was held in very high esteem by his Colleagues of the Permanent Commission, who will keep the best remembrances of him.

We wish to convey our sincerest sympathy to his family.

The Executive Committee.

NEW BOOKS AND PUBLICATIONS.

[625. 15]

WÖLTJEN (H), Engineer, Minden (Westphalia) — **Weichenbautechniches Handbuch** *(Manual on the utilisation of points and crossings in station layouts)*. — One volume (4 3/8×6 in.) of 592 pages with more than 400 figures, diagrams and tables, — 1959, Frankfort (Main) and Berlin-Zehlendorf, Dr. Arthur TETZLAFF-Verlag. (Price : bound in cloth, DM 12).

Some thirty years ago, a study group seconded from the Central Management of the German Railways, designed the « Reichsbahn » type standard points and crossings to take the place of the many different types in use that had belonged to the former State railways. After this considerable task was completed, there was a long gap before any further technical progress took place in connection with points and crossings. However, after the last war, it was found essential to make certain improvements, which led to the publication of a new edition and to bringing up to date the manual under this heading.

This manual is intended to serve as a guide when studying the layout of stations. The Bundesbahn, the successor of the Reichsbahn, has at the present time 21 basic points designs, 16 turnouts and 8 crossings; turnouts on curves are also derived from the basic types of points.

After the usual introduction, 54 pages are devoted to diagrams of the old type equipment still in service though abandoned in principle. The following 17 pages show dimensioned diagrams of the new type equipment, 45 in all. The next 52 pages are devoted to trigonometrical tables and other tables to facilitate the calculation of connections and points on curves. Then follow 315 pages giving dimensioned diagrams of a large number of groups of points and crossings realised in practice or realisable. The work ends with 133 pages of tables dealing with the fundamental components, in wood and metal, which are used in « Reichsbahn » type points and crossings.

This is an extremely useful manual for all those who have to deal with points and crossings of the German type.

A. J.

[656 (06 (43)]

Vorträge und Berichte des 2. Verkehrs- Wissenschaftlichen Tages der Hochschule für Verkehrswesen Dresden. *(Lectures and Reports of the Second Transport Science Days at Dresden Higher Transport School)*, 14/16 June 1958. — One volume (5 1/2 × 7 7/8 in.) of 200 pages with numerous illustrations. — 1958, Dresden. Compiled and published by the « Rektorat der Hochschule für Verkehrswesen, Dresden ».

The Higher Transport School of Dresden held in June this year its third meeting devoted to the study of transport sciences.

On this occasion, they have published the proceedings of the meetings and lectures organised at the previous meeting in 1956.

Thirty lectures were given. The subjects

covered deal with all aspects of railway science : organisation, operation, telecommunications, construction of the rolling stock, development of welding, electrification, fixed installations and infrastructure, the economics of transport.

For lack of space, only seven reports have been reprinted in full. These deal with automation on the railways, the organisation of marshalling yards, the use of welding in the maintenance of railway rolling stock, electric transmissions for Diesel stock, the prevention of slipping of the ground, and with productivity and wages in the transport undertakings of the German Democratic Republic.

In the case of the other lectures, a brief summary with bibliographical reference, if the matter in question has been published in the technical press, is given at the end of the book.

R. S.

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P. GHILAIN,

General Secretary of the Permanent Commission of the International Railway Congress Association.

(JANUARY 1960)

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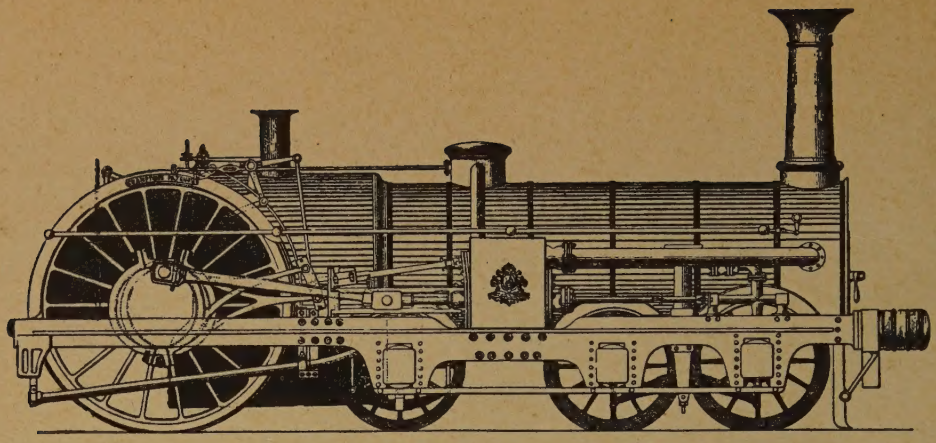

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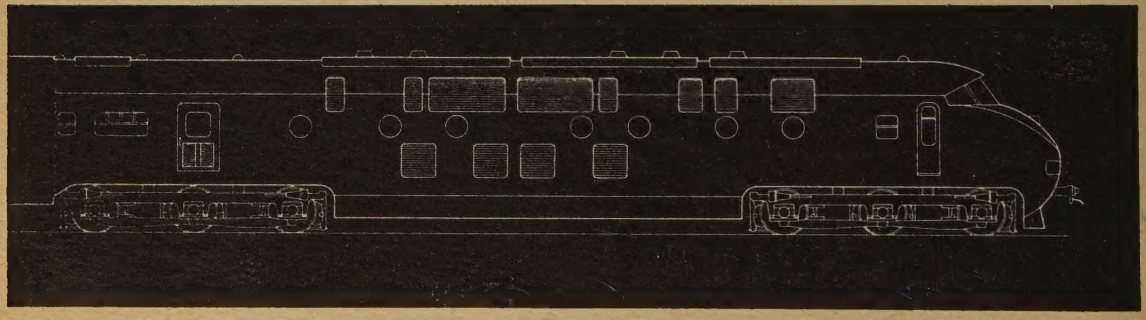

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